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NEW TRUTHS

IN

OPHTHALMOLOGY,

AS DEVELOPED BY

G. C. SAVAGE, M.D.,

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FIFTY-EIGHT ILLUSTRATIONS.

THIRD EDITION.

PUBLISHED BY THE AUTHOR.
PRINTED AT THE PUBLISHING HOUSE OF THE M. E. CHURCH, SOUTH.
NASHVILLE, TENN.
1896.

THE AUTHOR DEDICATES THIS LITTLE VOLUME

To the Memory of S. D. Gross, M.D., LL.D., D.C.L.,

WHOSE ADVICE GIVEN HIM WAS: "*STUDY A SPECIALTY;*"

AND

To George T. Stevens, M.D.,

WHOSE ORIGINAL WORK HAS BEEN OF INCALCULABLE VALUE TO HIM IN HIS SEARCH AFTER TRUTH, AS IT PERTAINS TO THE SCIENCE AND PRACTICE OF OPHTHALMOLOGY, HIS "STUDIED SPECIALTY."

Preface to the First Edition.

In presenting this little volume to ophthalmologists who read, the author feels that he is doing them a service that will be appreciated. He offers no apology for publishing what he believes to be new and valuable truths, after having demonstrated, to his own satisfaction, their practical value. He claims that the truths set forth in Part I., Chapters I., II., and V. are his by right of discovery and development; and that there is enough new in Chapters III., IV., and VI. to justify their being placed in Part I. In establishing the practical value of what is taught in Part I., the author is indebted to Dr. George H. Price for earnest and efficient coöperation.

Part II. is given as an expression of the author's views on the two long-studied subjects treated therein.

Part III. contains brief descriptions of five operations which are the author's either by device or modification.

In the body of this book, the author has mentioned by name those to whom he felt specially indebted for aid while " weaving his webs of thought." It only remains for him to acknowledge the aid rendered him by his brother, Prof. G. M. Savage, in the detection and correction of errors in both copy and proof; and to thank the several persons, in the great Publishing House, to whom was intrusted the mechanical work, for their faithfulness.

Nashville, Tenn., November, 1893.

Preface to the Second Edition.

Numerous requests for a copy of this book having come from the present class in the Medical Department of the University of Nashville and Vanderbilt University and from former graduates, the author decided to publish this special edition. After a conference with some who heard him deliver his "Charge to the Graduating Class of 1886–87," he decided that he would incorporate that address in this special edition.

Nashville, Tenn., December, 1893.

PREFACE TO THE THIRD EDITION.

IN presenting the third edition of this book to Ophthalmologists the author wishes to acknowledge that the increase in the size, over former editions, is largely due to the unfavorable criticisms of his views on oblique astigmatism and the oblique muscles, which emanated from his *confrères* Eaton, Hotz and Wilson. Mainly because of these criticisms, Chapters II., III., and IV. have been inserted. He leaves to the impartial judgment of his readers the decision as to the truthfulness of what he has taught on these subjects. He wishes to acknowledge his debt of gratitude to these critics, for, in their own way, they have aided him in presenting more clearly and forcibly his thoughts on oblique astigmatism and the oblique muscles.

In the preparation of Chapter IV. the author desires to acknowledge the aid given him by Lowry, his former pupil, and Perry.

The addition to Chapter V. makes the detection of insufficiency of the obliques most easy, and places the treatment of this condition on a sound scientific basis.

In Chapter VIII. the author believes that he has embodied valuable practical doctrine.

The development of weak ciliary muscles and the prevention, or at least the delay, of presbyopia is shown to be possible in Chapter IX.

In concluding this preface the author wishes to thank all editors who reviewed the first edition. These reviews were in the main kind and considerate. He wishes to deny the accusation of the few who said that the author did not believe that Solomon told the truth when he said: "There is nothing new under the sun." Principles are as old as the sun, and to these Solomon referred. The author is not responsible for the fact that some of the principles set forth in Part I. of this book were concealed through so many centuries, nor does he know why it fell to his lot to uncover them.

Nashville, Tenn., February 24, 1896.

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PART I.

New Truths in Ophthalmology.

CHAPTER I.

THE HARMONIOUS SYMMETRIC ACTION OF THE OBLIQUE MUSCLES IN ALL CASES OF OBLIQUE ASTIGMATISM.*

More than four years ago I became convinced from observation that a revolution of the eyes, on their antero-posterior axes of rotation, for the improvement of vision, occurs in all cases of oblique astigmatism. This conviction led me to develop a theory of revolution, which I made public for the first time in a paper entitled "The Function of the Oblique Muscles in Certain Cases of Astigmatism," read before the Section of Ophthalmology of the American Medical Association, at its Chicago meeting in 1887. A year later I wrote a second paper in reply to a paper on "Binocular Astigmatism," read by Dr. H. Culbertson before the Section

* Read before the Nashville Academy of Medicine, January 15, 1891.

of Ophthalmology, at the Cincinnati meeting of the American Medical Association, in which I advocated the same theory of rotation as set forth in my first paper, and by it accounted for all the phenomena referred to in Dr. C.'s paper, viz., loss of parallelism of the sides of a rectangle, slanting of a level surface, etc.

In developing my theory of rotation, I believed the teaching to be true that, under all circumstances, the naturally vertical meridians of the corneæ must be kept parallel, or double vision would result. I therefore reasoned that, in rotating, both eyes must roll in the same direction. This could be effected only by the superior oblique of one eye acting with the inferior oblique of the other; and this action I termed "harmonious non-symmetrical."

At that time the condition necessitating this revolving of the eyes was not clear to me. I contented myself by believing that the retinal image was thereby sharpened. That oblique astigmatism involves the necessity of abnormal action on the part of the oblique muscles, I will be able to prove in this paper, thus taking the rotation of the eyes on their antero-posterior "axes of rotation" out of the domain of theory and placing it in that of fact.

What is astigmatism? I cannot hope to answer this question more clearly than it is answered in many of the books on the eye. But many of you, not being Ophthalmic Surgeons, possibly have never read the chapter on astigmatism.

An astigmatic eye is one whose cornea has not the same radius of curvature for all its parts. That part of the cornea having the shortest radius is the most rapidly curved; while the part with the longest radius is the least rapidly curved. These two parts are always at right angles the one to the other.* As a rule the meridian of greatest curvature is in the vertical or nearly so; while the meridian of least curvature is nearly or quite horizontal. As we go from the meridian of greatest toward the meridian of least curvature we find every meridian less rapidly curved, hence each having a longer radius than the one preceding it.

The law of refraction by curved surfaces I will illustrate by supposing that we have before us two spheres of crown glass, one having a radius of two inches, and the other a radius of one inch. Parallel rays of light, on entering either of these spheres, will undergo such a bend at the points of entrance as will bring them to a focus at the opposite extremity of the diameter of the sphere. The larger sphere, having a diameter of four inches, has, therefore, a focal power of four inches; the smaller sphere, having a diameter of two inches, has a focal power of two inches. The density of the one sphere being the same as the density of the other, the difference in focal power is due solely to the want of similarity in curvature. The more rapidly curved

*The Ophthalmometer sometimes shows a slight variation from this rule.

surface has the shorter focus; the least rapidly curved surface, the longer focus.

As already defined, astigmatism is due to a want of similarity of curvature of the different parts of the cornea.

Figure A is intended to represent an astigmatic eye. The continuous and dotted curved lines to the left represent the meridians of greatest and least curvature of the cornea,

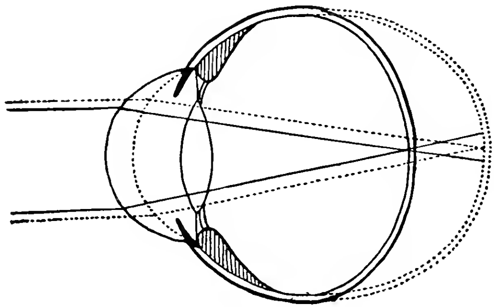

Figure A.

known in ophthalmology as the two principal meridians. These must be considered as at right angles to each other. The continuous line, which is the more rapidly curved, we will consider as the vertical meridian of the cornea; and as such it is destined to refract the rays of light entering the eye in the vertical plane. The two continuous parallel lines represent this plane of rays; and these, as shown in the figure, are so bent by this curved surface as to be brought to a focus on the retina, represented by the continuous curved line to the right. The broken curved line to the left, representing the horizontal meridian of the cornea, is less rapidly curved, and therefore so refracts the rays of light entering the eye in a horizontal plane (these are represented by the two broken parallel lines), as to give them a longer focal distance. You see them brought to a focus on the dotted curved line to the right, some distance behind the continuous line representing the retina. This difference in focalizing power affects alike both divergent and parallel rays of light.

To have a perfect image of any external object formed on the retina, all the rays emanating from any one point of the object must be brought to one point on the retina. For this to be, the cornea must be a section of a perfect sphere, all the meridians having the same radius of curvature. It is clear, then, that an unaided astigmatic eye cannot have a well-defined image of any object formed on its retina.

I need only mention that, in the two forms of hypermetropic astigmatism, the corneal meridian of greatest curvature is the *best* meridian, the focus for its rays being on the retina (as in simple hypermetropic astigmatism), or a little way behind it (as in compound hypermetropic astigmatism); while the focus for the meridian of least curvature is always more distant.

In myopic astigmatism, whether simple or compound, the meridian of greatest curvature is always the *worst* meridian.

In the fifth and last form, mixed astigmatism, the most rapidly curved meridian is the myopic; the least rapidly curved, the hypermetropic.

If you were all Ophthalmic Surgeons, it would be superfluous for me to add that regular astigmatism, which includes the five kinds just mentioned, is congenital in its origin; and its duration is commensurate with the lifetime of the individual. While there are opinions to the contrary, it is the conviction of the author of this paper that, so long as the astigmatic cornea remains free from pathological changes, the kind and quantity of the astigmatism remain invariable. That is to say, the radii of curvature of the two principal meridians bear at all times the same relationship to each other.

What effect has astigmatism on the retinal image? Suppose the object looked at to be a line occupying a position at right angles to the meridian of best curvature. Its image will be more or less sharp, depending on the quantity of astigmatism, except at its two extremities, which will be blurred. If the line corresponds to the best meridian, the whole image is so marred that the line is not well seen. If the two principal meridians are respectively vertical and horizontal, the retinal image of a horizontal or vertical object is unaffected except in sharpness of outline as indicated above.

In all cases of oblique astigmatism there is something more than a simple blurring of the image. In eyes free from astigmatism, and even in astigmatic eyes when the principal meridians are vertical and horizontal, the horizontal object and the retinal image are always in the same plane. In oblique astigmatism, be the obliquity much or little, it is a physical impossibility for the horizontal object and its retinal image to occupy the same plane. The same is true of all objects not in a plane with one or the other of the two

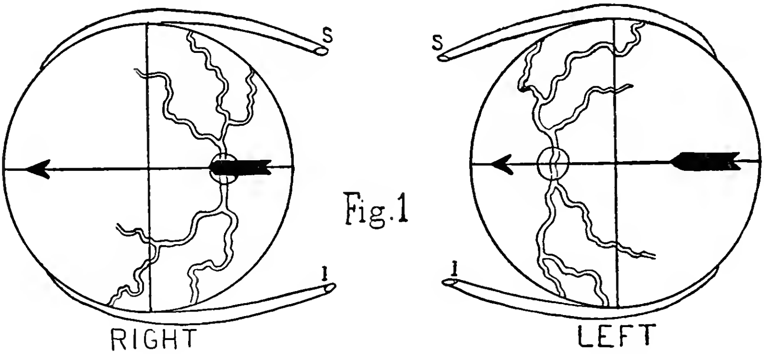

Fig. 1

principal meridians. There is, therefore, not only blurring, but also obliquity of the image.

Figure 1 represents a pair of eyes in which the two principal meridians are vertical and horizontal (they can also represent eyes that are non-astigmatic). If before these eyes an arrow, or the picture of an arrow, be held horizontally, the arrowhead toward the patient's left, it will throw a reversed image on each retina, and the two images will be in the same plane with the object. These two images fall on parts of the two retinæ that act together, hence but one object is seen.

Figure 2 represents a pair of eyes in which there is hyper-

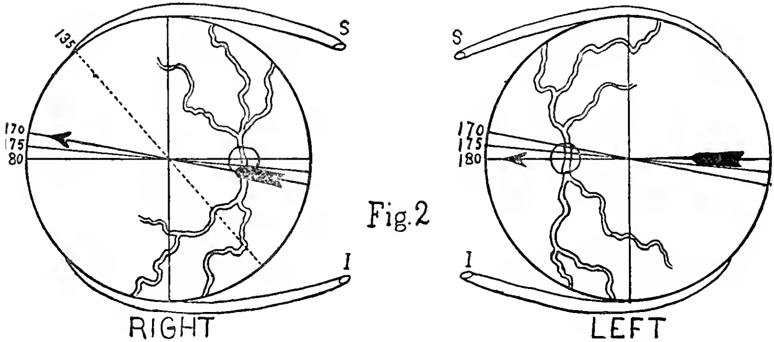

Fig. 2

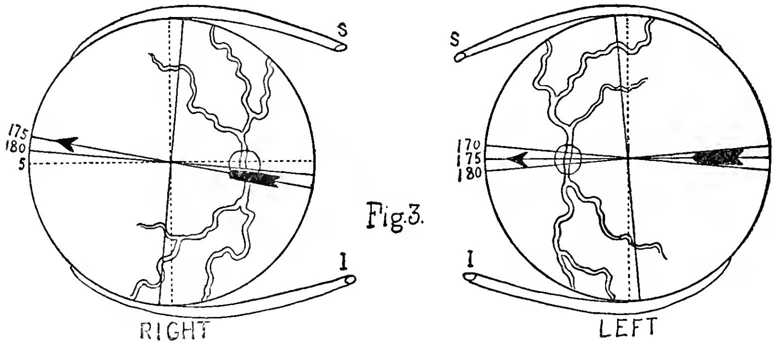

Fig. 3.

metropic astigmatism, either simple or compound. The left eye has its best meridian vertical. In this eye the arrow, held as before, throws its image on the horizontal meridian of the retina, hence in the same plane with it. In the right eye the best meridian is at 135°, as shown by the dotted line. In obedience to the well-known law of refraction by curved surfaces, the image of the same arrow must be oblique in

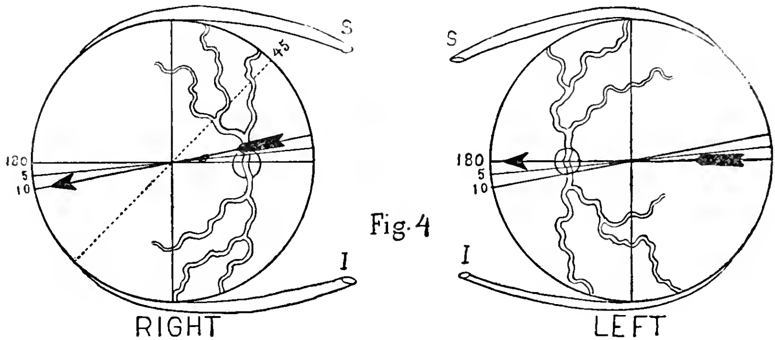

Fig. 4

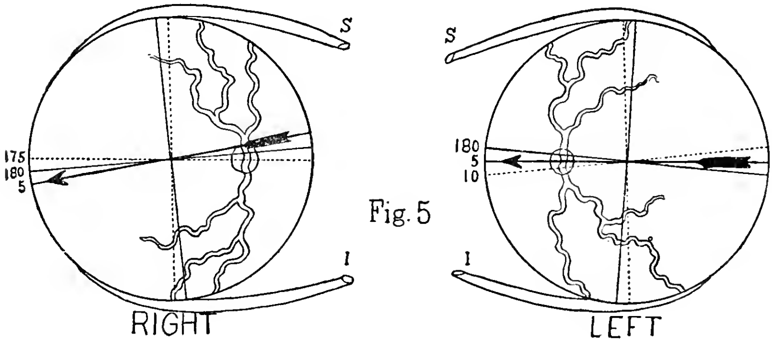

Fig. 5

this eye, and hence not in the same plane with the object. The obliquity of the image will be greater or less, depending on the quantity of the astigmatism. I represent it as falling on meridian 170° of the retina. The horizontal image in the left eye and the oblique image in the right eye do not fall on parts of the two retinæ that harmonize. The direction of either image in relation to the other cannot be

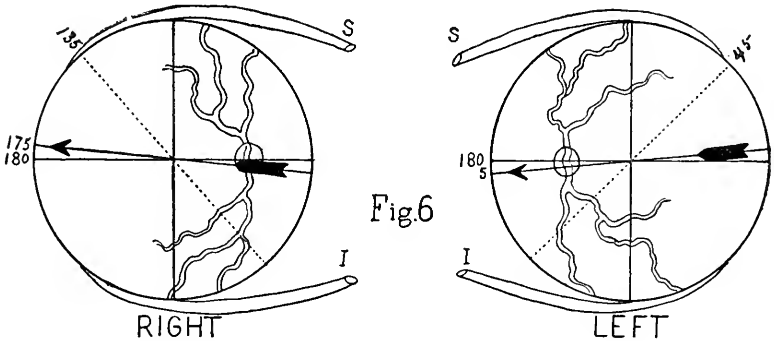

Fig. 6

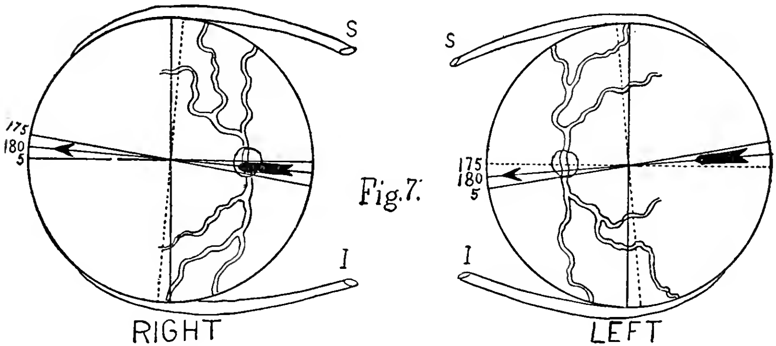

Fig. 7.

changed except by artificial means—a proper cylindrical lens. This being true, the pair of unaided astigmatic eyes, represented by Figure 2, must see the arrow double, as shown in Figure 8, unless something is done by the eyes themselves for the purpose of harmonizing the images. What is done will be shown later.

Figure 4 represents a pair of hypermetropic astigmatic eyes, the left one having its best meridian vertical, and the right one having its best meridian at 45°. In these eyes there is a left horizontal image (image and arrow in same plane) and a right oblique image, this time on retinal meridian 10°. Nothing but artificial means will change the relative direction of these images; and there must be double

Figure 8.

vision, unless the oblique image can be made to fall on a portion of the retina that will harmonize with that portion of the other retina on which the horizontal image may fall.

Figure 6 represents a pair of hypermetropic astigmatic eyes, with half the quantity of astigmatism found in the eyes represented by Figures 2 and 4; but in both eyes the best meridian is oblique, in the left at 45°, and in the right at 135°. An arrow held in the horizontal position before these eyes will throw an oblique image on each retina; the one in the left eye on meridian 5°, and the one in the right on meridian 175°. Without some change double vision, as shown in Figure 8, will be inevitable.

In the same way I could demonstrate the obliquity of retinal images in oblique myopic astigmatism. The rule in oblique astigmatism, without a single exception, is this: *The retinal image is displaced toward the meridian of greatest curvature; therefore, in oblique hypermetropic astigmatism, the image is displaced toward the meridian of best curvature; in myopic astigmatism, from the meridian of best curvature; and in oblique mixed astigmatism, toward the myopic meridian.*

The obliquity of the image in oblique astigmatism is demonstrable. One who is emmetropic, or at least is nonastigmatic, by placing a —3 D. cyl. before each eye in trial frames, creates 3 dioptres of hypermetropic astigmatism. The axis of the left cylinder being at 90° and that of the right at 135°, he has made of his own eyes the kind represented by Figure 2. He may now for a moment place the opaque disk in front of his right eye, at the same time placing the double prism (each 6°) before the left eye. A horizontal arrow, head to left, having been drawn on a card board, he looks through his double prism and sees two horizontal, hence parallel, arrows. On removing the opaque disk from the right side of the trial frame, a third arrow appears between the other two, but not parallel with them—it is oblique down and to the patient's left. On removing the double prism two arrows are at once readily seen, the one crossing the other as in Figure 8. In a moment the two arrows begin to shut and open like the blades of a pair of scissors; and finally they are merged indefinitely into one.

What efforts are made by the eyes for the correction of astigmatism? In some forms of astigmatism, the ciliary muscle labors to improve the state of vision, to sharpen the retinal image. When the rays of light come to the eye parallel, no form of ciliary strain can improve the vision in myopic astigmatism, simple or compound. For divergent rays in low degrees of myopic astigmatism, regular ciliary contraction may so act on the lens as to cause the focal interval to fall on the retina, whereby a sharper retinal image is formed.

In hypermetropic astigmatism, the rays of light being either parallel or divergent, regular ciliary contraction can so act on the lens as to make the focal interval fall on the retina, and thus sharpen vision.

In myopic astigmatism the best meridian being either in the horizontal or vertical, there can be no strain in distant seeing, for no kind of strain would improve the vision; but there may be ciliary strain in near vision. In hypermetropic astigmatism, non-oblique, there is only ciliary strain both for distant and near seeing.

Sectional contraction of the ciliary muscle for the partial or complete correction of astigmatism has its advocates. Martin developed the theory. The ciliary muscle is supposed to act in two opposite sections; while the balance of this circular muscle remains quiet, or is in a slighter state of action. The parts in greatest action are supposed to coincide with the corneal meridian of least curvature. It is argued that in this way lenticular astigmatism is produced, of the same kind as, but at right angles to, the corneal astigmatism. If this be true, then in non-oblique myopic astigmatism, distant seeing is not attended by sectional ciliary contraction, since it would make vision worse and not better—distant vision in simple myopic astigmatism of 1 D. is better than when there is 1 D. of simple myopia. The object of all eye-strain is to improve vision; and when this cannot be effected, the strain is not instituted. In myopic astigmatism near vision would be greatly improved by sectional ciliary strain.

In hypermetropic astigmatism sectional ciliary contraction could sharpen both distant and near vision. Granting that there may be, now and then, a case of "masked" hypermetropic astigmatism, which would point to the correctness of Martin's theory of sectional ciliary contraction, the great mass of evidence gathered from daily observations, by whomsoever made, goes to prove that there is no truth in his theory.

In all cases of oblique astigmatism, unless the obliquity is in the same direction in the two eyes, and the astigmatism the same in kind and quantity, something must be done in order to prevent double vision, as represented in Figure 8.

There are but two ways of accounting for the absence of this peculiar kind of double vision in such forms of astigmatism as that represented in Figures 2 and 4. Sectional ciliary contraction would account for it. If it were possible for the ciliary muscle thus to act, one can readily understand how the curvature of the lens could be so changed as to result in lenticular astigmatism equal, but at right angles, to the corneal astigmatism. If such ciliary action were to take place in the right eye of either Figure 2 or 4, the retinal image would not only be made as sharp as if in an emmetropic eye, but it would also be made to lose its obliquity, and thus double vision would be prevented. As beautifully as this sectional ciliary action would account for the absence of double vision in cases of oblique astigmatism, it is certainly a false theory, since, when all ciliary power has been suspended by atropine or age, the eyes are still able to do something by means of which the double vision represented by Figure 8 is prevented.

If sectional ciliary contraction does not occur, then the two eyes represented by Figure 2 or 4 have no inherent power by means of which the relative direction of the two retinal images can be changed; hence there must be double vision, unless the oblique image in the right eye and the horizontal image in the left can be made to occupy corresponding parts of the two retinæ. This can be effected alone by the *harmonious symmetrical action of the oblique muscles.*

Figure 3 shows how the eyes represented by Figure 2 act in order to have the images fall on corresponding parts of the retinæ. The superior oblique muscle of the right eye has so revolved it as to bring meridian 175° of the retina in position to receive the impress of the oblique image; while at the same moment the superior oblique muscle of the left eye has so revolved it as to bring meridian 175°, to the horizontal, hence in position to receive the horizontal image. The oblique and horizontal images being now on harmonizing portions of the retinæ, there is no double vision.

The double vision that would exist in astigmatic eyes represented in Figure 4 is prevented by the harmonious action of the inferior oblique muscles, as shown by Figure 5, the inferior oblique of the right eye bringing meridian 5° under the oblique image, while the inferior oblique of the left eye causes meridian 5° to come under the horizontal image. Thus the two images are made to fall on corresponding parts of the two retinæ.

In the oblique astigmatism of the two eyes represented by Figure 6, the two oblique images are made to fall on corresponding parts of the retinæ by the harmonious action of the two superior oblique muscles, as shown in Figure 7.

The obliquity of the image and the consequent strain on the oblique muscles fully account for the greater trouble attending oblique astigmatism than is found connected with astigmatism in the vertical or horizontal. As has already been shown in this paper, non-oblique myopic astigmatism is unattended by any sort of strain in distant vision.

In oblique myopic astigmatism, there is strain on either the two superior or two inferior oblique muscles in both distant and near seeing. In all other forms of oblique astigmatism, there is likewise strain on the oblique muscles.

In all kinds of non-oblique astigmatism, also in simple hypermetropia, the time comes when all nervous phenomena caused by their existence pass away. Their disappearance, being gradual but finally complete, coincides with the failure and final loss of ciliary power brought about by advancing age. The symptoms caused by oblique astigmatism may be modified by old age putting at rest the ciliary muscles, but they cannot be made to vanish; for the oblique muscles are forced to continue to act in age as in youth, so as to harmonize the images on the two retinæ.

It is easy to account for the little suffering endured by one person with a certain quantity of astigmatism oblique in a certain direction, while another person with the same condition of refraction is a greater sufferer. Let us suppose two persons having eyes represented by Figure 2. The necessity for overaction or abnormal action is on the superior oblique muscles. In the case of the one who suffers but little the superior obliques are powerful and can bear the necessary strain without generating a train of nervous phenomena; in the other patient the superior oblique muscles are feeble, and the necessary overwork is attended by periodical waves of suffering.

The propriety—I may say the necessity—of correcting non-oblique astigmatism by means of cylindrical lenses is now universally acknowledged. Such a lens sharpens the retinal image, thus making the object clear and distinct, and at the same time removes the necessity for abnormal ciliary strain. In youth, headaches and other symptoms, whose existence depends on this strain, vanish as if by magic when the correct cylindrical lenses are worn. Otherwise old age alone would relieve the sufferer without being able to sharpen the image.

In oblique astigmatism the correcting lens both sharpens the retinal image and causes it to lose its obliquity, thus, at one stroke, destroying the necessity for abnormal ciliary strain and for overaction on the part of the oblique muscles. The one set of symptoms whose existence is lost in advancing age, and the other set whose duration is commensurate with the length of life, are made to disappear by the power of the cylindrical lens.

In the several cuts showing the effect of oblique astigmatism on the retinal image of a horizontal arrow, the best meridian is 45° either out or in from the vertical. This position for the meridian of greatest curvature was chosen because, for any given quantity of astigmatism, the obliquity of the retinal image is greatest here. If there are several cases of hypermetropic astigmatism of 3 D. each, one of these, having its best meridian at 100° (or 80°), will have a retinal image only slightly oblique; another, with its best meridian at 110° (or 70°), will have more obliquity of its retinal image; and so on, until the case is reached in which the best meridian is at 135° (or 45°). Here the maximum of obliquity of the image is reached. In the remaining cases, the best meridians are between 135° (or 45°) and the horizontal; and the nearer these are to the horizontal, the less oblique are the images. What is true of hypermetropic astigmatism is also true of the myopic and mixed forms of astigmatism. The obliquity of the image varies not only with the difference in position of the meridian of greatest curvature, but also with varying quantities of astigmatism. The image will not be so oblique if there is 1 D. of astigmatism with its best meridian at 135° (or 45°) as when there are 2 D. in the same direction. The amount of obliquity of the retinal image of any horizontal object varies, in any given quantity of astigmatism, with the more or less remote position of the meridian of greatest curvature from the vertical or horizontal up to 45°; also with the quantity of astigmatism, the best meridian being at some fixed angle between the vertical and horizontal. In small degrees of astigmatism, the obliquity of the image can be but a few minutes, while in the higher degrees the obliquity is 5° or more. In some of the figures used illustrating this paper, the obliquity of the image is represented as being as much as 10°, only for convenience of illustration.

All errors of refraction should be corrected by the examination of only one eye at a time, an opaque disk being placed in front of the other eye; and the eyes should be under the influence of a mydriatic, unless ciliary strain has been suspended by age. Especially should this be the plan of procedure in all cases of oblique astigmatism. It is in cases of oblique astigmatism that oculists find trouble in locating the axis of the cylinder, at one moment the patient indicating that it should be at a certain angle, and at the next moment 5° or more removed from this point.* Enough time should be spent, and sufficient care exercised, to enable the operator to determine the natural location of the best meridian; and at this angle the axis of the cylinder should always be placed. If the best meridian in hypermetropic astigmatism is in the temporal quadrant, and there is doubt as to whether the axis of the cylinder should be placed at a certain angle or 5° nearer the horizontal, the latter should be chosen; for in such a case the superior oblique, from long habit, wants to continue to revolve the eye in an abnormal but, without the proper cylinder, necessary position. The point to be chosen for the location of the

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* We have also been able to show that insufficiency of the obliques adds to the difficulty of properly placing the axis of the cylinder. See chapter on Insufficiency of the Obliques.

axis of the cylinder in myopic astigmatism is always the reverse of that for hypermetropic astigmatism—I mean where there is doubt between any two points.

Each of the two eyes in which there is oblique astigmatism having thus been carefully corrected, the proper glasses are ordered. When the patient begins to wear them, his binocular single vision is nearly always disturbed by an apparently changed condition of objects, a rectangle no longer appearing to be such, and a level surface seeming to incline. Sometimes the changes are so marked as to make the patient very uncomfortable. This metamorphopsia (so termed by Dr. Lippincott, of Pittsburg) may continue a few hours, a day, a week, or a month, but in the end is certain to disappear It is due to a continuation of the old habit of rotation, when both eyes are used, and a consequent loss of coincidence of the best meridians and the axes of the cylinders. Whenever this now unnecessary habit of rotation is broken, be it soon or late, sudden or gradual, the metamorphopsia ceases. The different forms of metamorphopsia can be demonstrated artificially.

Four years ago I said that in cases of oblique astigmatism the eyes were made to rotate by means of the oblique muscles. I repeat the assertion to-day with emphasis, but with this modification: I then thought the rotation was effected by the *harmonious non-symmetrical* action of the obliques; but in this paper I have demonstrated that the rotation is brought about by the *harmonious symmetrical* action of the obliques, and have also shown why the rotation is necessary.

The only papers ever published, touching this question, so far as I know, except my own already referred to, are: one on "Binocular Astigmatism," by Dr. H. Culbertson, in the Journal of the Association, November 3, 1888; and one on "Metamorphopsia," by Dr. J. A. Lippincott, in the Archives of Ophthalmology, March, 1889. The latter is a valuable paper, and shows the Doctor to be a close observer as well as a ready writer. In his paper he incidentally refers to the obliquity of the retinal image in oblique astigmatism, but does not advocate the doctrine of rotation.

Founded on the teachings of this paper, Dr. N. C. Steele, of Chattanooga, formulated the following working rule:

"*In those cases in which the axes of the proper convex cylinders for the two eyes diverge, place the cylinders at those points which will give the axes the greatest divergence permitted by the tests; and in those cases in which the axes converge, place them at the points which will give them the greatest convergence permitted by the tests.*"

In oblique myopic astigmatism the placing of the axes of the concave cylinders is governed by the above rule, modified by substituting *least* for *greatest* and *vice versa* wherever it occurs. This rule is applicable only in those cases where there is doubt as to the location of the axes. When one eye of a pair of oblique astigmatic eyes is covered, the strained oblique muscles do not always relax; and when this is the case, the cylinder given does not relieve the strain, however sharp it may make the vision. In some cases, the obliques do relax, one eye being covered, and the cylinders are readily so placed as to relieve all strain. In these two conditions the answers of the patients throw no doubt on the question of location of the axes of the cylinders. There are other cases, and they are numerous, in which there is alternating contraction and relaxation of the obliques, the one eye being covered while the other is under observation. At one moment the patient declares that he sees best with the cylindrical axis at one point, and at the next moment he selects a point 5° removed. This is kept up until no conclusion can be reached, unless the operator has knowledge of the nature of oblique astigmatism. It is in such cases as these that Dr. Steele's rule may be safely followed; and that, too, without having to stop to determine whether the superior or inferior obliques are the strained pair.

CHAPTER II.

THE FUNCTIONS OF THE OBLIQUE MUSCLES, ESPECIALLY AS THEY ARE RELATED TO OBLIQUE ASTIGMATISM.*

THE common purpose of all the extrinsic ocular muscles is the production of binocular single vision, in obedience to the law of corresponding retinal points. The recti muscles are designed to control the visual axes, while the obliques are concerned with the corneo-retinal meridians. In model eyes a plane may be constructed so as to cut the macula and the nodal point of each eye and that point of the object to be fixed. The superior and inferior recti must keep the two visual axes in this plane, while the external and internal recti must direct them so that they may intersect at the point to be fixed. Since, in all eyes free from oblique astigmatism, all other visual lines bear a definite relationship to the visual axis, they may be ignored in any study of the ocular muscles. If the recti muscles, in accomplishing the purpose of their existence, effected no other change of the eyes, there would be no need for oblique muscles in eyes not having

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oblique astigmatism. The three axes of rotation are at right angles to one another, their point of intersection being the nodal point—the center of retinal curvature. The lateral recti muscles, if properly attached to the globe, will rotate it only on the perpendicular axis; the superior and inferior recti could not, if unopposed, effect the rotation of the eye on its transverse diameter, and hence would cause a form of double vision, in spite of the fact that they would keep the visual axes in the normal plane. In order to insure binocular single vision, other muscles are needed besides those that govern the visual axes; and these muscles are the obliques.

If there were no such condition as astigmatism, or if the principal meridians in astigmatic eyes were always vertical and horizontal, there would be but one function for the oblique muscles, and that function would be the keeping of the naturally vertical meridians of the corneas parallel, and their study would be greatly simplified. The prime object of this paper, however, is to show that the obliques have another and more complicated function to perform in many cases. Taking causes into consideration, we may say that the one function of the obliques is simple, while the other is complicated.

The Simple Function of the Obliques

is keeping the naturally vertical meridians parallel. The need for this exists in all eyes, whatever may be the state of refraction other than oblique astigmatism. Even in oblique astigmatism, equal in amount in the two eyes and the meridians of greatest curvature being parallel, only the simple function is performed by the obliques. The necessity for this function of the obliques resides mainly in the action of

THE SUPERIOR AND INFERIOR RECTI,

which is faulty in all cases, because of the course of these muscles and their attachment to the globe. When the inferior recti are called upon to direct the visual axes below the horizontal plane of the two eyes, they, at the same time, tend both to converge these axes and to rotate the eyes so that the naturally vertical meridians would diverge above. To counteract this latter tendency the superior obliques are thrown into a state of activity, and the parallelism of the vertical meridians is maintained. When the visual lines are to be directed above the horizontal plane, by contraction of the superior recti, these muscles, besides tending to converge the axes, also tend to converge the vertical meridians above, to counteract which the inferior obliques are brought into a state of activity, and thus parallelism is preserved.

If the tendons of the internal and external recti attach themselves in greater part below the horizontal plane of the eye, these muscles, in adducting and abducting the eyes, would tend to revolve them so that the vertical meridians of the corneas would diverge above. This tendency would be counteracted by the superior obliques. Should the lateral muscles be attached to the globe mainly above the horizontal plane, adduction and abduction would be associated with a tendency to converge the vertical meridians above, which would be prevented by the action of the inferior obliques. It is probable that the one or the other error of attachment of the internal and external recti is not uncommon.

Thus it is seen that, with every contraction of the inferior recti, there must be an associated corrective contraction of the superior obliques; and that, with every action of the superior recti, there is an accompanying and correcting action of the inferior obliques. Since we look down far more than we look up, the superior oblique muscles, in the same proportion, are made to do more work than the inferior obliques. Thus it is readily seen that the recti and oblique muscles, while opposing one another in action to a certain extent, work together in effecting binocular single vision, by keeping the two retinæ so related that the images fall on corresponding parts.

Plate I. represents a pair of eyes that are non-astigmatic; or, if astigmatism exists, the principal meridians are vertical and horizontal. These eyes are represented as looking at a rectangle. The line *cp* across the right eye is the horizontal meridian and the line *gh* is the vertical meridian, while their point of intersection (5) is the macula. Similarly the line *cp* in the left eye represents the horizontal meridian, and *gh* the vertical meridian, their point of intersection (5) being the macula. The vertical meridian of the right and

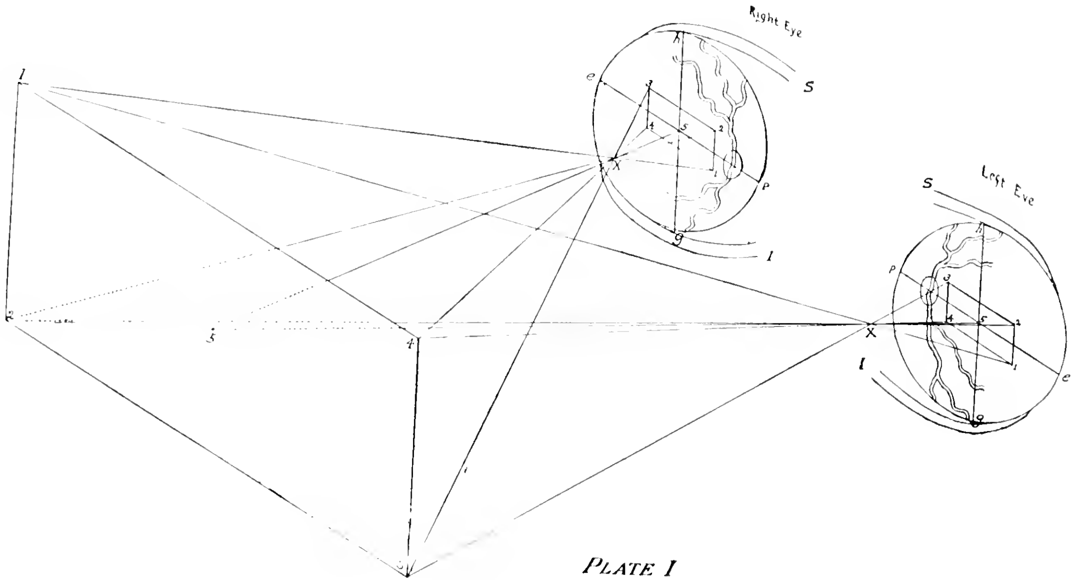


Plate I

that of the left are parallel. Point 5 in the rectangle is the point of fixation. The line 5-5 from the macula of the right eye is the visual axis of that eye, and likewise the line 5-5 is the visual axis of the left eye. These intersect at point 5 of the rectangle.

According to the well-known law of refraction by curved surfaces, such as are now under consideration (non-astigmatic eyes), the rectangular object will throw a rectangular image on each retina, the size of which will bear a definite proportion to the size of the object. The nodal point of the right eye is *x*, through which all lines of direction from this eye must pass. The lower inner corner of the image is thus connected with the upper right-hand corner of the object by the line 1-1. In the same way the upper inner corner of the image is connected with the lower right-hand corner of the object by the visual line 2-2; and so on for the other corners of image and object. In like manner the corners of the rectangular image in the left eye may be connected with corresponding corners of the object by lines passing through the nodal point (*x*) of that eye. If the left eye should be excluded, the right eye would see the rectangle 1-2-3-4; if the right eye should be screened, the left would see the same rectangular figure. Both eyes together, in obedience to both the law of corresponding retinal points and the law of projection, would see the one common rectangle 1-2-3-4. The superior and inferior recti in these eyes have kept the visual axes in the normal plane, the external and internal recti have regulated their tension so that they have converged these axes to the point 5, and the superior and inferior obliques have kept the naturally vertical meridians parallel.

It has already been stated that the obliques have to perform only the simple function in oblique astigmatism, when the meridians of greatest curvature are parallel and the degree of astigmatism is the same in the two eyes; and yet it would not be possible for such eyes to see the rectangle held in the position shown in Plate I. as a rectangle. Let the meridians of greatest curvature be at 45° in the right and also at 45° in the left eye. As a result of the refraction of the astigmatic cornea of the right eye, the rectangular figure would throw a parallelogram image on the retina, the image inclining down and out. A parallelogram image would be thrown on the left retina also, and it would incline down and in. Looked at with either eye alone, the rectangle would be seen as a parallelogram inclined down and to the right; looked at with both eyes, it would be a parallelogram of the same shape and inclination as seen by each eye separately. The extrinsic muscles of these eyes have performed the same function as the muscles of the eyes shown in Plate I., and with the same result—viz., binocular single vision. The law of corresponding retinal points and the law of projection having full sway in both pairs of eyes, the one pair sees the figure as it is—a rectangle—while the other pair sees the same figure, when held in the same position, as a parallelogram leaning down and to the right. With the visual axes properly directed by the recti, and the vertical meridians kept parallel by the obliques, the two eyes are kept so related that the two images of the object looked at fall on harmonizing parts of the two retinæ, and the object is necessarily seen as one, and of the same shape as when seen with each eye separately.

In any state of refraction the relationship between corresponding points of the two retinæ is unalterable. It is well known that, taken as a whole, the nasal half of one retina harmonizes with the temporal half of the other, and that all points of either retina bear a fixed and unalterable relationship to the macula and to the vertical and horizontal meridians. A retinal point in the nasal half of the right retina, bearing a definite relationship to the macula and the vertical and horizontal meridians, must harmonize with a point in the temporal half of the left retina similarly located; and it can harmonize with no other retinal point under any conditions.

THE COMPLICATED FUNCTION OF THE OBLIQUES is necessary in oblique astigmatism when the meridians of greatest curvature diverge or converge above. This is necessary that they may bring harmonizing parts of the two retinæ under dissimilar images, and thus insure binocular single vision; but, as will be shown, the object, though seen as one, will be distorted.

Plate II. may be taken for study. Both eyes have oblique astigmatism of the same kind and quantity. In the right eye the meridian of greatest curvature is at 135° and in the left at 45°. As set forth in a former paper, the refraction in oblique astigmatism is such as to make vertical and horizontal lines incline toward the meridian of greatest curvature. If the rectangular figure represented in Plate I. be held in the same position before the eyes represented in Plate II., it would not be seen with one eye alone or with both together as a rectangle. The rectangle shown in Plate I., when held before the right eye in Plate II., instead of throwing a rectangular, would throw a parallelogram image on the retina. The same rectangle would also throw a parallelogram image on the left retina. The state of refraction of the right eye would make the distorted image lean down and toward the left, while the distorted image in the left eye would lean down and toward the right side. Cutting off the view of the left eye, the law of direction would have full sway, while the law of corresponding points would be suspended. Since in one eye alone the law of direction is unalterable, all lines of direction must cross in the center of retinal curvature; and the right eye, with the parallelogram image leaning down and to the left, must see the figure casting the image, not as a rectangle, but as a parallelogram leaning down and to the left. Screening the right eye while the left looks on the rectangle, it is seen, not as a rectangle,

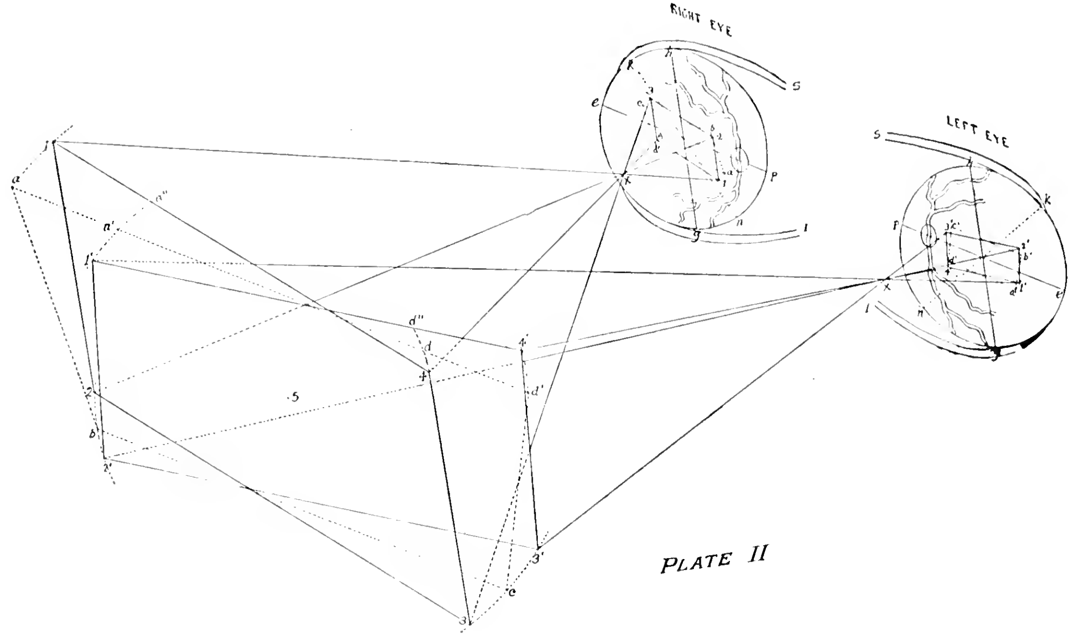


PLATE II

but as a parallelogram leaning down and to the right, the law of direction determining the shape of the figure seen by the left eye just as it fixed the shape of the figure seen by the right eye. Fig. 1-2-3-4 is what is seen with the right eye alone; fig. 1′-2′-3′-4′ is what is seen by the left eye alone. The moment these two eyes are allowed to look at the rectangular figure, the law of corresponding retinal points is brought into conflict with the law of direction; and the latter is modified by the former. There is no necessity for changing the visual axes when looking at the rectangle with these two eyes; but, unless some change is effected in some way, each eye would see its own parallelogram leaning down and toward the opposite side. Instantly a change does take place in both eyes, so that the two together see, not a rectangle nor a parallelogram, but a trapezoid with the longer side above. A clear understanding of what this change is and how it is effected may be had by a further study of Plate II. In the right eye is shown a dotted parallelogram *a-b-c-d*, of precisely the same form as the parallelogram image 1-2-3-4, but in the former the upper and lower lines are parallel with the horizontal meridian. In the left eye also is shown a dotted parallelogram *a′-b′-c′-d′*, of the same form as the parallelogram 1′-2′-3′-4′, with its upper and lower lines parallel with the horizontal meridian of this eye. The line *c-d* in the right eye bears throughout the same relation to the macula, the horizontal and vertical meridians of this eye, that the line *c′-b′* does to the same parts of the left eye, and therefore correspond. The greater part of the line *d-a* in the right eye also corresponds with the greater part of the line *d′-a′* in the left eye, the parts of these lines not corresponding being their extremities. But the line *c-d* in the right eye nowhere corresponds with the line *c′-d′* in the left except at the points of beginning above; and the same is true of lines *b-a* and *b′-a′*, in their respective eyes. If the dotted parallelograms could be made to coincide with the parallelogram images, the result would be that the two eyes together would see the figure *a-b-c-d′*, a trapezoid with the longer side above. How this is effected is shown in Plate III., where each eye has been revolved on its visual axis by the superior oblique muscle, so that the horizontal meridian is made parallel with the upper and lower borders of the parallelogram image; and thus as far as possible corresponding parts of the two retinæ are brought under the two dissimilar images, and the figure seen binocularly is *a-b-c-d′*. The part of this trapezoid seen in common by the two eyes is *a′-b-c-d*, the part seen by the right alone is *a-b-a′*, and that seen by the left eye alone is *d-c-d′*. As will be seen, the law of corresponding points has so modified the law of projection that the visual lines no longer have a common crossing point. This is anarchy, so far as projection is concerned, in these eyes.

When the law of direction is interfered with, as a result of the conflict between it and the more imperious law of corre-

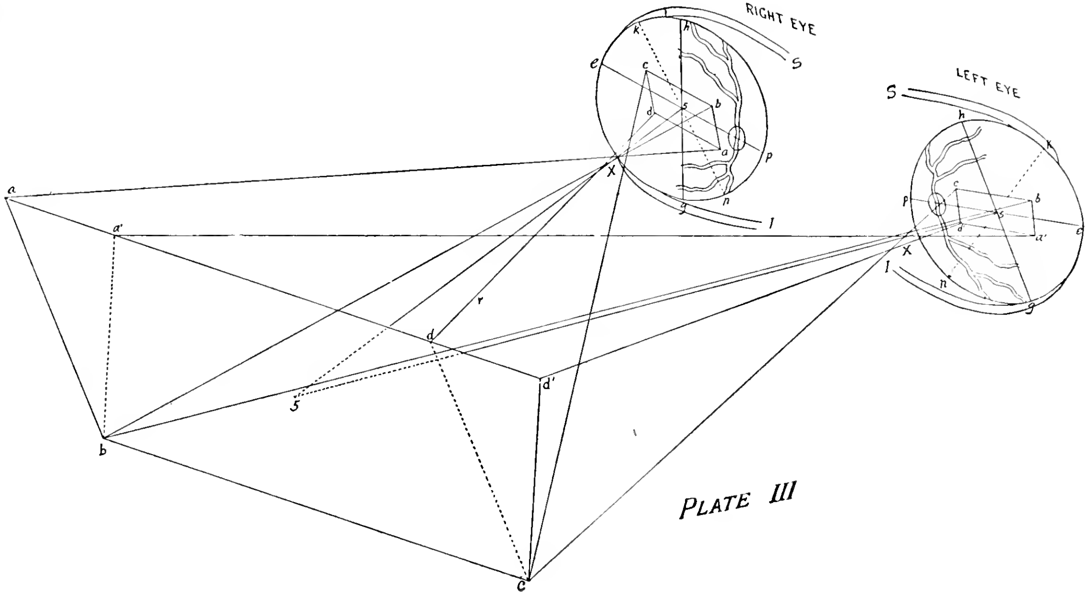


PLATE III

sponding retinal points, the object seen is always in the position that it would have been in, had the images primarily fallen on the parts of the two retinæ that have been rotated under them (by either the recti or the oblique muscles) in obedience to the supreme law of binocular single vision—the law of corresponding retinal points. The displaced images, as a result of either natural or artificial means, cover areas of the two retinæ that do not correspond. In order to have binocular single vision, retinal areas that do correspond, and are of same shape and size as the images, must be brought under them. The object will be seen as though no rotation had taken place, as if the images had primarily fallen on these parts, in perfect obedience to the law of projection, although the lines of direction drawn from the images to the single object will not cross at the nodal point. In cases of decentration of the maculæ, and in displaced images by means of prisms, all lines of direction will cross at one point, but that point will be above, below, to the outer or inner side of the true nodal point; while in oblique astigmatism, and when the axes of correcting cylinders are displaced, no three lines of direction cross at the same point.

In like manner a plate could be made showing how astigmatic eyes, with meridians of greatest curvature converging above, would see a rectangle distorted into a trapezoid, the longer side below. In each eye there would be a parallelogram image inclining down and out. To fuse these into a trapezoid the inferior oblique muscles would be brought into action, in order, as far as possible, to bring corresponding retinal parts under dissimilar images, which is done the moment the obliques displace the horizontal meridians, so that they become parallel with the upper and lower borders of the distorted images.

Imperfect as is binocular single vision in uncorrected oblique astigmatism, the meridians of greatest curvature either diverging or converging above, it could be effected in no other way than by a revolution of the eyes by the symmetric harmonious action of the oblique muscles. It is true that nature has one other method of preventing diplopia, mental suppression of one of the displaced images. It may be that amblyopia resulting from oblique astigmatism high in degree, and from insufficiency of the obliques, is more common than one would at first think. Certainly, if the obliques cannot do their proper work in effecting binocular single vision, in the first years of life, nothing is more reasonable than to suppose that amblyopia *ex anopsia* would develop. Who has not seen cases of amblyopia without being able to account for it?

The phenomena outlined in this paper can be demonstrated experimentally by any one who desires to prove all things; for he can produce in his own case, at pleasure, any form of astigmatism. But some may be ready to say that artificial astigmatism is one thing and natural astigmatism is another thing. This is true, but only in name. That 3 D. of artificial hypermetropic astigmatism is the same error of refraction as 3 D. of natural hypermetropic astigmatism is abundantly proved by the fact that each is thoroughly corrected by a + 3 cylinder, axis properly placed. Either plus or minus cylinders may be used in the experiments, for the one is as capable of producing artificial astigmatism as the other; if the plus cylinders (3.00 D.) be used, the astigmatism produced has its meridian of greatest curvature at right angles to the axis of the cylinder, while the meridian of greatest curvature would correspond with the axis of the minus cylinders (3.00 D.) if they were used.

By either means it can be easily proved that in astigmatism of any kind (myopic, hypermetropic, or mixed), whose meridians of greatest curvature diverge above, there is a necessity for action on the part of the superior oblique muscles in order to prevent diplopia. This action, having its beginning in the earliest days of infancy and continuing during waking hours until the cause is corrected or one eye is lost, converges the naturally vertical meridians above. If the meridians of greatest curvature converge above, the images of all objects are so displaced in the two eyes as to throw into activity the inferior obliques, so that diplopia may be prevented.

In astigmatism with the principal meridians vertical and horizontal, the only eye muscles brought into action, to remedy in any way the condition, are the ciliary muscles. In oblique astigmatism with the meridians of greatest curvature diverging above, there is the same state of ciliary strain to sharpen as much as possible the images, and there is also a necessary activity of the superior obliques so as to bring corresponding parts of the two retinæ under the oblique images, that there may be binocular single vision. Again, in oblique astigmatism with the meridians of greatest curvature converging above, there is the ciliary strain for sharpening the images, and there is also a consequent activity of the inferior obliques so as to bring similar parts of the retinæ under the dissimilar images, resulting in binocular single vision.

When there is equality of strength of the obliques of the two eyes, vertical and horizontal astigmatism will give less trouble than when the astigmatism is oblique in either direction, and astigmatism with the meridians of greatest curvature diverging above need give no more annoyance to the patient than if these meridians converged above when the plane of vision is horizontal; for, in the former case, the superior obliques would be as able to bear the strain as would the inferior obliques in the latter condition. When the meridians of greatest curvature diverge above and the plane of vision (visual axes) is directed down, as in reading, the added strain on the superior obliques would give more annoyance than if, in the same patient, the meridians of greatest curvature converged above; for the reason that, in the latter, the simple action of the superior obliques to overcome the tendency to outward rotation of the eyes by the inferior recti would, to that extent, relieve the tension of the inferior obliques excited by the astigmatism.

But the obliques are not always harmonious. The superior obliques are insufficient in at least 25 per cent. of all cases, while the inferior obliques are insufficient in less than 1 per cent. of all cases. In cases of insufficiency of the superior obliques, the vertical form of astigmatism would be worse on the patient than if he had oblique astigmatism with the meridians of greatest curvature converging above; and the worst form of astigmatism would be that in which the meridians of greatest curvature diverge above. The reverse would be true if the inferior obliques were insufficient—a rare condition.

The complicated function of the oblique muscles exists only in cases of oblique astigmatism with meridians of greatest curvature converging or diverging above, and in unequal degrees of oblique astigmatism when the meridians of greatest curvature are parallel. The necessity for this function is entirely destroyed when the astigmatism is properly corrected; but the action of the obliques does not always cease at once in binocular single vision through the correcting cylinders. The old habit of rotation often continues for hours, and sometimes for days, although there is no longer a need for it, and the result is metamorphopsia. Inherent weakness of the superior oblique muscles, in a large per cent. of the cases, leads to a more speedy disappearance of the metamorphopsia when the meridians of greatest curvature diverge above than when they converge. The reverse would be true in a case of insufficiency of the inferior obliques. The *habit* of action is more quickly suspended in a weak muscle than in a strong one. In all cases, however, it ceases, and the metamorphopsia vanishes, under the continuous wearing of the correcting cylinders.

Artificial conditions may excite the obliques into the performance of either their simple or complicated function, depending on the means used. A prism placed base up before one eye would call into action the inferior rectus of that eye. This action would tend to turn the vertical meridian out above, which tendency would be at once counteracted by action of the superior oblique so as to keep that meridian parallel with the vertical meridian of the fellow-eye. A prism, with base up, before the right eye, and one with base down before the left would call into action the inferior rectus of the right and superior rectus of the left, and there would be an associated and corrective action of the superior oblique of the right and inferior oblique of the left, if the vertical meridians are to be kept vertical. In this case, however, the naturally vertical meridians being still parallel, though not vertical, are most likely allowed to remain tilted, since diplopia would not result.

Prisms placed bases out before the eyes will call into action the internal recti in obedience to the law of corresponding points. If these muscles are attached neither too high nor too low, other muscles will not be affected by the prisms; but if these muscles are attached too low, their forced action will tend to make the naturally vertical meridians diverge above, when a corrective action of the superior obliques becomes necessary; or if the attachment is too high, the inferior obliques act to prevent the convergence of the vertical meridians above. The indirect effect, on the oblique muscles, of prisms in position of rest for weak recti muscles, may account largely for the unsatisfactory results of that once common plan of treatment.

In the rhythmic exercise treatment of the internal recti muscles, a state of insufficiency of the superior obliques is sometimes developed that was not manifest in the beginning even under the proof tests. The only explanation is that the internal recti in these cases are attached too high, and their exercise has been necessarily associated with corrective rhythmic action of the inferior obliques, so that they become too strong for the superior obliques. These cases do not improve as they should, until proper attention is given to the superior obliques. In only two instances have I seen insufficiency of the inferior obliques develop as a result of exercise of the interni; and it is easy to suppose that in these cases the interni were attached too low, and that consequently their exercise was associated with corrective rhythmic contraction of the superior obliques, resulting in their hyperdevelopment. These cases did not do well until attention was given to the inferior obliques in connection with the treatment of the interni.

The effect of prisms on the externi, under conditions of too high or too low attachment, would bring about a secondary effect on the obliques, precisely as has been described in connection with the interni. In either case the obliques are performing their simple function, that of keeping the naturally vertical meridians parallel.

The complicated function of the obliques may be excited by artificial means also. As already stated, artificial oblique astigmatism calls into harmonious symmetric activity either the superior or inferior obliques, depending on the divergence or convergence above of the meridians of greatest curvature.

In the correction of any form of astigmatism, the proper location for the axes of the cylinders should always be determined, as a variation in either direction would throw strain on the oblique muscles, which would be badly borne in proportion to the strength of the displaced cylinders and the extent of their deviation. Several curious facts may be brought forward here, and reasons can be given why advantage should be temporarily taken of these facts in certain cases. Fig. 1, in Plate IV., represents a pair of hyperme-

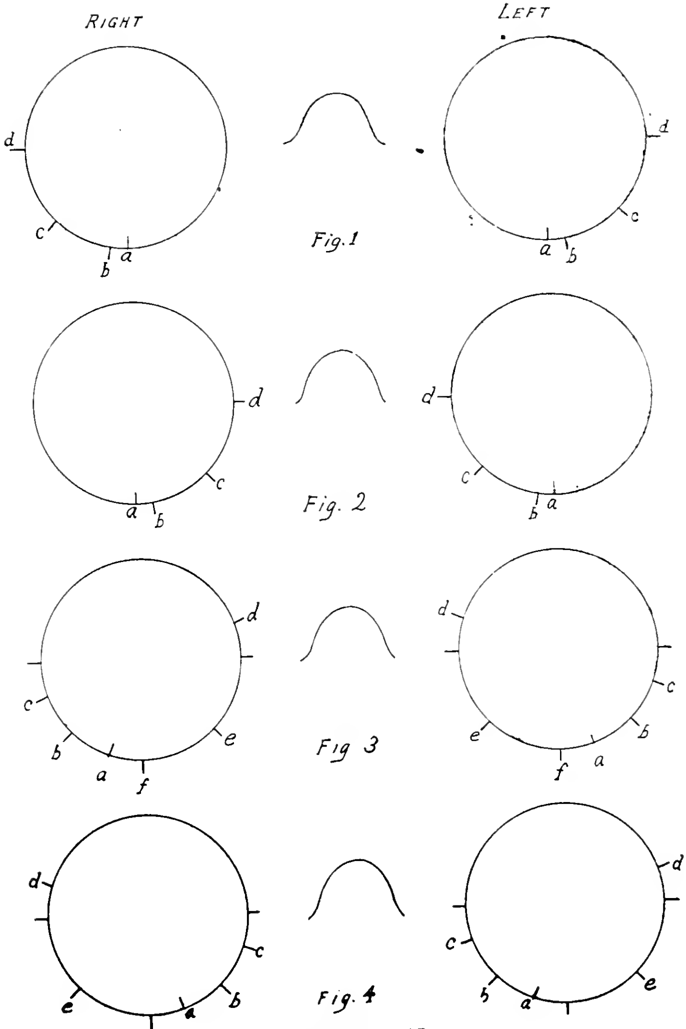


PLATE IV

tropic astigmatic eyes, the meridians of greatest curvature being vertical in each eye. The plus cylinders, axes 90° (*a*), insure against strain of either the superior or inferior obliques; but let the glasses be turned in their rims so that the axis of the right shall stand at 80° (*b*) and the axis of the left at 100° (*b*), images will be distorted, as shown in Plate II., which would necessitate strain on the part of the superior oblique muscles. The distortion of the images would increase, and the strain on the superior obliques would be greater, as the axes are revolved farther away from the vertical, the maximum being reached at 45° (*c*) for the right, and 135 (*c*) for the left eye. Passing these points the distortion grows less, until at 180° (*d*) for each eye it disappears.

Fig. 2 represents the same pair of eyes. If now the axis of the right cylinder should be revolved from 90° (*a*) to 100° (*b*) and that of the left from 90° (*a*) to 80° (*b*), the distortion of images would be such as to call into activity the inferior obliques, so that there might be binocular single vision. This distortion would reach its maximum when the axis of the right cylinder stands at 135° (*c*) and that of the left at 45° (*c*), again lessening as the axes are made to approach the horizontal, where the distortion ceases.

Fig. 3, Plate IV., represents a pair of hypermetropic astigmatic eyes with the meridian of greatest curvature for the right at 70° (*a*) and that of the left at 110° (*a*). (In all the figures of plates IV., V., and VI., the mark within the circle shows the location of the meridian of greatest curvature.) These meridians converging above would cause strain on the inferior obliques, which would be relieved by the correcting cylinders, axis of the right at 70° (*a*) and of the left at 110° (*a*). A revolution of the axis of the right cylinder to 45° (*b*) and that of the left to 135° (*b*) would so displace the images as to call into action the superior obliques, the displacement increasing as the axes are moved until these points (*b* for each eye) are reached. Continuing the revolution of the cylinders in the same directions, the displacement lessens, and disappears entirely when the axis of the right reaches 20° (*c*) and that of the left 160° (*c*); and the necessity for action of the obliques no longer exists. If the axes of the cylinders are moved from their correct positions (70° for the right and 110° for the left eye) to 90° (*f*) for each eye, images will be so displaced as to call into corrective activity the inferior obliques. The maximum of displacement would be effected when the axis reaches 135° (*e*) in the right and 45° (*e*) in the left eye. Continuing the revolution in the same directions, the displacement would grow less, and finally disappear when the axis of the right stands at *d*, and that of the left at *d*, each 20° above the horizontal. As will be seen, the arc of distortion, so as to throw strain on the superior obliques, is 50° (from 70° to 20° in the right eye, and from

110° to 160° in the left eye), while the arc of distortion that would throw strain on the inferior obliques is 130° (from *a* to *d*).

Fig. 4, Plate IV., shows the meridians of greatest curvature of these hypermetropic astigmatic eyes at 110° (*a*) for the right and 70° (*a*) for the left. These meridians diverging above, would call into corrective activity the superior oblique muscles. Correctly chosen and properly placed cylinders, by correcting the distortion of the images, would remove the necessity for the performance of the complicated function of the superior obliques. Displacing the axes of these cylinders, the right to 135° (*b*) and the left to 45° (*b*), would cause a maximum of distortion of the images, of the kind to call into action the inferior obliques. Continuing the revolution of the cylinders, the distortion would disappear when the axis of the right reaches 160° (*c*) and that of the left 20° (*c*). Should the axes of the cylinders be revolved from their proper places—at 110° (*a*) in the right and 70° (*a*) in the left—to 90° (*f*) for each eye, the images would be so changed as to call into harmonious activity the superior obliques. The maximum distortion would occur when the axis of the right is at 45° (*e*) and that of the left at 135° (*e*). Continuing the revolution, the distortion would disappear when the axes reach the points *d* above the horizontal meridians. In this case the arc of distortion causing activity of the inferior obliques is 50° (from *a* to *c*) while the arc of distortion that would throw strain on the superior obliques is 130° (from *a* to *d*). If in this pair of eyes the meridians of greatest curvature had been at 130° for the right and 50° degrees for the left, the arc of distortion that would call the inferior obliques into action would be only 10°, while the one that would cause activity of the superior obliques would be 170° (180° less 10°).

Fig. 1, Plate V., represents hypermetropic astigmatic eyes, the meridians of greatest curvature being at 180° (*a*) in each eye, a condition that, in itself, would not call either the superior or inferior obliques into activity. The correct plus cylinders, axes 180°, would sharpen the blurred but not distorted images. Displacing these axes in the lower temporal quadrants would so distort the images as to throw into action the superior obliques; and the maximum of distortion would be effected when the axes reached 45° (*c*) in the right and 135° (*c*) in the left eye. With the axes turned to 90° (*d*) there would be no distortion of images, though there would be blurring, as in all cases of displaced cylinders.

Fig. 2, Plate V., represents the same pair of eyes shown in Fig. 1. The axes of the correcting cylinders revolved in the lower nasal quadrant would so distort images as to call into action the inferior oblique muscles, the maximum being effected when the axes stand at 135° (*c*) for the right and 45° (*c*) for the left eye, the distortion lessening as the axes

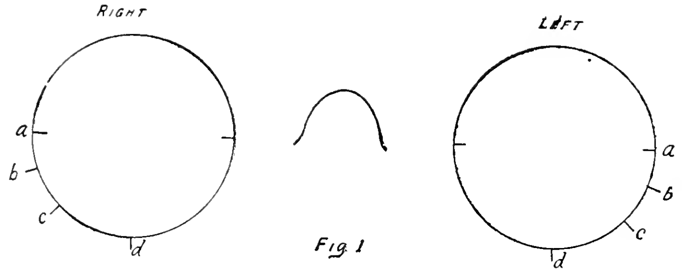


Fig. 1

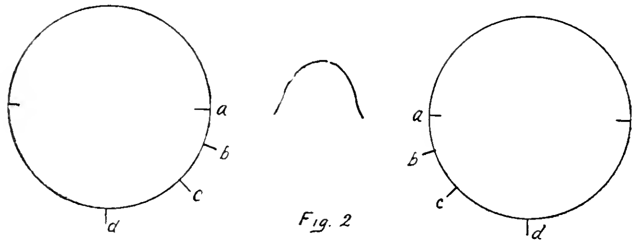


Fig. 2

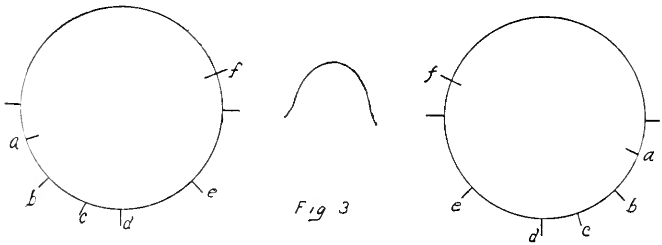


Fig 3

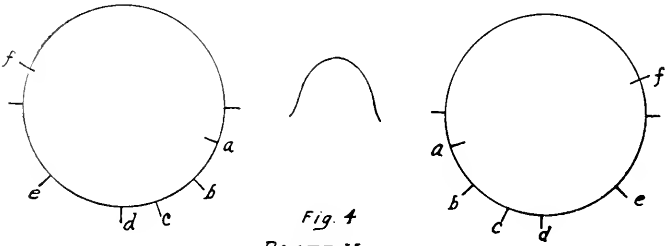


Fig. 4

PLATE V.

approach, and disappearing altogether when they reach 90° (*d*).

A comparative study of Figs. 1 and 2 of Plate IV., with Figs. 1 and 2 of Plate V., will show that in hypermetropic astigmatism with the meridians of greatest curvature either vertical or horizontal, a revolution of the axes of the cylinders in the lower temporal quadrant will distort images (as of a rectangle) down and in, and thus will call into harmonious action the superior obliques; and it will also show that a revolution of the cylinders in the lower nasal quadrants will so displace the images as to call into harmonious action the inferior obliques.

Fig. 3, Plate V., represents a pair of hypermetropic astigmatic eyes with the meridian of greatest curvature for the right eye at 20° (*a*) and that of the left at 160° (*a*). Since these meridians converge above, the uncorrected condition would cause harmonious action of the inferior obliques. Properly chosen and correctly placed cylinders, axes at 20° (*a*) for the right and 160° (*a*) for the left eye, would relieve the distortion of the images and do away with the necessity for the complicated function of the obliques. Revolving the axis of the right cylinder from 20° (*a*) to 45° (*b*) and that of the left from 160° (*a*) to 135° (*b*) would cause a maximum displacement of images in such a way as to call into action the superior oblique muscles, the distortion disappearing when these axes reach 70° (*c*) for the right and 110° (*c*) for the left eye. Passing 70° (*c*) in the right and 110° (*c*) in the left, the distortion becomes reversed, so that the strain will be thrown on the inferior obliques, the maximum being attained when the axis of the right stands at 135° (*c*) and that of the left at 45° (*c*). The distortion decreases as the axes are still farther turned in the same directions, and disappears at the end of the arc of 130° (from *c* to *f*) when they coincide with the meridians of greatest curvature. Thus the arc of distortion involving the superior obliques is 50° (from *a* to *c*) while that involving the inferior obliques is 130° (from *c* to *f*).

The eyes (hypermetropic astigmatic) represented by Fig. 4, Plate V., have their meridians of greatest curvature at 160° (*a*) in the right and 20° (*a*) in the left. These meridians diverging above would result, in the uncorrected case, in calling into harmonious action the superior obliques. Proper cylinders with the axis of the right at 160° (*a*) and that of the left at 20° (*a*) would correct the distortion of the images, and relieve the strain on the superior obliques. A turning of these cylinders in the arcs *a*-*c* would distort the retinal images so as to bring into action the inferior oblique muscles, the maximum distortion existing when the axes are at *b*. Continuing the revolution from *c*, the distortion becomes reversed, and as a consequence the superior obliques are brought into activity, the maximum being attained when the axes reach *e*. As the axes are revolved farther the distortion lessens, and finally disappears when they stand at *f*, again coinciding with the meridians of greatest curvature. In this pair of eyes the arc of distortion involving the inferior obliques is 50° (from *a* to *c*), while that involving the superior obliques is 130°, the maximum of distortion in both instances being attained when the halfway point of the arc is reached by the axis of the cylinder.

A comparative study of any two, or of all the figures in Plates IV. and V. will show that the arc of distortion, by corrective plus cylinders, involving the superior obliques, is always in the lower temporal quadrant wholly or in greater part; and if entirely within this quadrant, its length is always twice the distance from the meridian of greatest curvature to the 45° point of the quadrant, the other half being on the opposite side of the latter. In like manner it will be seen that the arc of distortion involving the inferior obliques, by a revolution of plus cylinders, is always in the lower nasal quadrant wholly or in greater part; and if entirely within the quadrant, its length is twice the distance from the meridian of greatest curvature to the 45° point of the quadrant, the other half being on the opposite side of the latter. When the arc of distortion involving the superior obliques is 90°, that involving the inferior obliques is 90°, and *vice versâ*. When the arc of distortion involving the superior obliques is less than 90°, the arc involving the inferior obliques is always the difference between the former and 180°, and *vice versâ*. The maximum of distortion is always attained when the axis of the cylinder is at the halfway point of the arc.

Fig. 1, Plate VI., represents a pair of hypermetropic astigmatic eyes, the meridian of greatest curvature of the right at 45° (*a*) and that of the left at 135° (*a*). These meridians converging above would cause such distortion of images as to throw into harmonious action the inferior oblique muscles. The proper cylinders, correctly placed—axis of the right at 45° (*a*) and the axis of the left at 135° (*a*)—would counteract the distortion, and relieve the inferior obliques of the necessity of acting. Revolving the axes of the correcting cylinders in either direction would so distort images as to call into harmonious action the inferior oblique muscles. Since the arc of distortion for the superior obliques in this case is nothing, the arc of distortion for the inferior obliques is 180°, from *a* to *d* in either direction, the maximum of distortion being attained respectively at *e* above and at *c* below.

Fig. 2, Plate VI., represents a pair of the same kind of eyes, but with the meridian of greatest curvature at 135° (*a*) for the right and 45° (*a*) for the left. These meridians diverging above, the refraction is such as to distort images so as to call into harmonious action the superior obliques. As in the other case, the correct cylinders, properly placed, counteract the distortion, and relieve the superior obliques from action. Rotating the axes of these cylinders in either direction from *a* would so distort images as to call into activity the superior obliques. In this case the arc of distortion for the inferior obliques is nothing, and therefore the

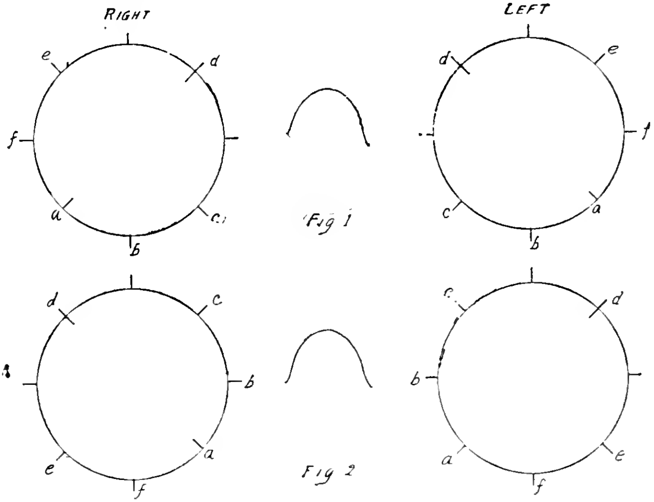


PLATE VI

arc of distortion for the superior obliques is 180°, from *a* to *d* in either direction, the maximum being attained at *c* above and *e* below.

A careful study of Plates IV., V., and VI. is fraught with practical importance. In all cases the exact location of the meridian of the best (greatest in hypermetropic astigmatism) curvature should be sought for with the greatest care, and may always be found; and the lens should be cut so that its axis may coincide with this meridian, although, as will be shown farther on, it may not always be best so to place it at first in the frames. Based on the teachings of my paper on the "Harmonious Symmetric Action of the Oblique Muscles in Oblique Astigmatism," published more than three years ago, Dr. N. C. Steele, of Chattanooga, Tenn., U. S. A., formulated a perfect working rule for determining the position of the best meridian in hypermetropic astigmatism, there being in the given case no insufficiency of the oblique muscles. The fellow-eye being covered, the eye under examination, no longer being dominated by the law of corresponding points, is likely at times to roll into the easy position (naturally vertical meridian becoming vertical) by a relaxation of the muscles accustomed to overacting in binocular single vision. This, of course, would cause the meridian of greatest curvature to slightly vary its position, the variation being in proportion to the amount of obliquity of the astigmatism and the quantity, but rarely, if ever, amounting to more than 5°. If the best meridian is in the lower temporal quadrant, and there is doubt between two points 5° apart, the axis of the plus cylinder should be placed at the higher; if the best meridian is in the lower nasal quadrant, and there is doubt between two points 5° apart, the axis of the plus cylinder should likewise be placed at the higher point. Steele's rule in all cases of oblique hypermetropic astigmatism is: "In those cases in which the axes of the proper cylinders for the two eyes diverge above, place the cylinders at those points which will give the axes the greatest divergence permitted by the tests; and in those cases in which the axes converge above, place them at the points which will give them the greatest convergence permitted by the tests."

While the above rule, in cases free from insufficiency of the oblique muscles, is a perfect one, so far as finding how the lenses should be cut is concerned, it is not, even in these cases, the rule to be followed in the immediate placing of the lenses in the frames. After a time, however, the cylinders cut according to the Steele rule should be so placed permanently.

In the case represented by Fig. 3, Plate IV., since the meridians of greatest curvature converge above, the inferior obliques have always been accustomed to overacting, while the superior obliques, to the same extent, have been accustomed to doing less work than would have been required of them in eyes free from oblique astigmatism. Placing the axis of the right cylinder at 70° (*a*) and that of the left at 110° (*a*) would at once take away the cause for overaction on the part of the inferior obliques. The necessity for work so suddenly taken from them is just as quickly transferred to the superior obliques, and as a result, in most cases, either there is suffering excited, the superior obliques responding to the new demand, or there is metamorphopsia, these muscles rebelling for the time against the new conditions brought about by the cylinders. Both the suffering and the metamorphopsia may be avoided by revolving the cylinders in the rims, so that their axes are made to traverse the arc (*a-d*) of distortion for the inferior obliques to the extent of 5° to 10°. The distortion will create the necessity for action on the part of the inferior obliques of the kind to which they have always been accustomed. Since the cylinders are made to describe larger arcs than the meridians of greatest curvature are made to traverse by the action of the inferior obliques, there will not be coincidence of the axes of the cylinders and meridians of greatest curvature; and vision to that extent will be blurred, though sharper than if no cylinders were on. Beginning with the cylinders thus displaced, they should be revolved 1° or 2°, every second or third day, back toward the equilibrium positions of the meridians of best curvature. Each backward move will take away part of the necessity for work from the inferior obliques, transferring the same quantity of work to the superiors. Thus by degrees the work is transferred from the inferior obliques to the superiors, and that, too, without exciting either discomfort or metamorphopsia. In this case it would be a serious mistake to displace the axes in the arc (*a-b*) of distortortion for the superior obliques; for, to the work transferred from the inferior to the superior obliques, there would be added the contraction necessary to harmonize the distorted images.

In like manner it could be shown that the axes of the cylinders for correcting the astigmatism represented in Fig. 4, Plate IV., should be temporarily placed 5° or 10° from their permanent places in the arcs (*a-d*) of distortion for the superior obliques. As in the case represented in Fig. 3, Plate IV., the axes should be gradually revolved back to their permanent resting place.

In any case of oblique astigmatism with meridians of greatest curvature converging above (see Fig. 3, Plate IV.; Fig. 3, Plate V.; and Fig. 1, Plate VI.), there being no insufficiency of the inferior obliques, the axes of correcting cylinders should be temporarily displaced 5° or more within the arcs of distortion for the inferior obliques, and gradually revolved back to their proper permanent points. Since there is no arc of distortion for the superior obliques in the eyes shown in Fig. 1, Plate VI., the temporary displacement may be either up or down from *a*.

In any case of oblique astigmatism, with meridians of greatest curvature diverging above (see Fig. 4, Plate IV.; Fig. 4, Plate V.; and Fig 2, Plate VI.), there being no insufficiency of the superior obliques, the axes of the correcting cylinders should be temporarily displaced 5° or more in the arcs of distortion for the superior obliques, the backward change being effected by degrees, so as to gradually transfer work from one muscle to the other. Since there is no arc of distortion for the inferior obliques in the eyes shown in Fig. 2, Plate VI., the temporary displacement of the axes may be either above or below the points *a*.

So far, in speaking of the arcs of distortion for oblique muscles, plus cylinders have been in mind. When minus cylinders are required, what would be the arc of distortion for the superior obliques, if plus cylinders were used, becomes the arc of distortion for the inferior obliques, and *vice versâ*.

Unfortunately there is not always perfect equilibrium of the oblique muscles in oblique astigmatic cases. If, as is most common, there is insufficiency of the superior obliques, oblique astigmatism with meridians of greatest curvature converging above will give but little trouble, as compared with astigmatism in which these meridians diverge above; and for the very good reason that in the former there is harmonious strain on the strong inferior obliques, while in the latter there is harmonious strain on the weak superior obliques.

Uncorrected oblique astigmatism with meridians of greatest curvature converging above, associated with insufficiency of the superior oblique muscles, is far more endurable than is the most perfect correction of the astigmatic error that can be made, when the insufficiency itself is ignored. On the other hand, when insufficiency of the superior obliques complicates oblique astigmatism with the meridians of greatest curvature diverging above, the correcting cylinders give immediate relief, and become a joy forever.

If it is important in cases of oblique astigmatism, not associated with insufficiency of the superior obliques, to displace temporarily the axes of the cylinders in the arcs of distortion for the inferior obliques, it becomes doubly necessary to do so when there is insufficiency of the superior obliques as a complication; and if these axes are ever to be revolved back, so that they shall coincide with the proper principal meridians, the weak obliques must be first developed by exercise.

There is another, and very proper method of correcting oblique astigmatism, especially that form in which the meridians of greatest curvature converge above. As already pointed out, the distortion of images (meridians of greatest curvature converging) is such as to throw work on the inferior oblique muscles. A partial (say one-fourth) correction of the astigmatism will slightly relieve the distortion of the images, and will thus transfer one-fourth of the work from the inferior obliques to the superior obliques. Having used the quarter correction for a few days, a half correction might be given, when another fourth of the distortion of images is relieved, and a proportionate amount of work is again transferred from the inferior to the superior obliques. After another period of a few days, a three-quarter correction could be given; and so on to the full correction, thus gradually giving the patient full acuity of vision, and as gradually transferring work from the inferior to the superior obliques.

CHAPTER III.

THE OBLIQUE MUSCLES AS RELATED TO OBLIQUE ASTIGMATISM: REPLY TO DR. HOTZ'S CRITICISM.*

Mr. Editor: With your kind permission, I will occupy a part of your space in answering the criticism of my views on the action of the oblique muscles in oblique astigmatism, as published by Dr. F. C. Hotz, in your last issue. Allow me first to plead guilty to the charge of having "talked" much, and "written" more, on this subject. I plead guilty, further, to the charge of having taught one thing (harmonious non-symmetric action) in 1887 and another thing (harmonious symmetric action) in 1891. To have taught an error is to no man's credit. It was my good fortune, however, to detect this error. I quickly exposed the incorrectness of my 1887 teaching—just as quickly as if another had been the unfortunate one. The main thought of my first paper was that oblique astigmatism was more annoying than the vertical or horizontal, because in the former the oblique muscles were involved. This was no error. I then knew nothing of the obliquity of images in oblique astigmatism; and, believing the old teaching that the oblique

*Published in *Annals of Ophthalmology and Otology*, July, 1895.

muscles must always keep the naturally vertical meridians parallel, I readily fell into the error of teaching that the action of the obliques caused by oblique astigmatism was "harmonious non-symmetric." I at that time conceived the purpose of the rotation to be to bring the meridian of best curvature to, or as far as possible toward, the vertical or horizontal position, a work in which the obliques were often aided by a leaning of the head toward the shoulder. I then thought that vertical (and horizontal) astigmatism gave least trouble, because of the mere fact of position; but now I can understand why oblique astigmatism, with meridians of greatest curvature parallel, will give as little trouble, for in each of these conditions any object will throw similar images on corresponding retinal parts. For the reason that the obliques do not have to perform their complicated function in these forms of astigmatism, their correction is never attended by metamorphopsia or other annoyance.

I try always to "have a reason for the faith that is within me," and any change of faith or teaching on my part must be based on reason. My reason for abandoning the teaching of harmonious non-symmetric action of the obliques in oblique astigmatism, and in its place teaching that these muscles must act symmetrically, is that the refraction of such eyes causes the formation of dissimilar images on non-corresponding parts of the retinæ. This thought of oblique images in oblique astigmatism occurred to me one night early in 1891, and the next day I was able to demonstrate its correctness, not only to my own satisfaction, but also to the complete satisfaction of Dr. G. H. Price. I did not then remember that Dr. J. A. Lippincot had taught us this in the *Archives of Ophthalmology*, March, 1889.

Dr. Hotz complains that I have not given my "method of observation," and that I failed to set forth "the tests or experiments" that led me to my conclusions, so that others

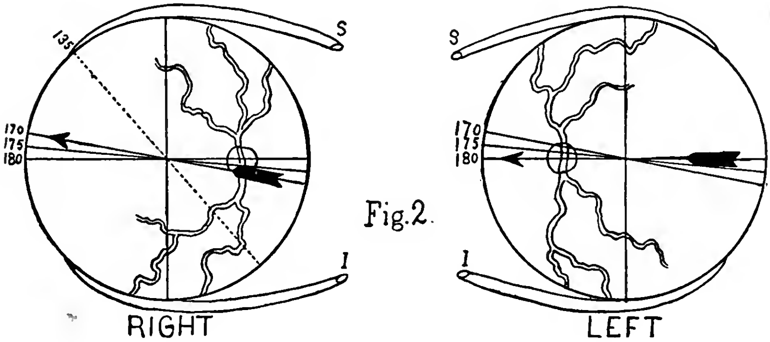


FIGURE I.

might judge for themselves as to the correctness of the same. This accusation was certainly inadvertent, for a little farther on (page 105 of your last issue) he quotes my experiment in part. I give it here in full:

"The obliquity of the image in oblique astigmatism is a matter demonstrable. One can artificially produce any kind of astigmatism. One who is emmetropic, or at least is non-astigmatic, by placing a —3 D. cylinder before each eye in trial frames, creates 3 dioptres of hypermetropic astigmatism. The axis of the left cylinder being at 90° and that of the right at 135°, he has made of his own eyes the kind represented by Fig. 2 [Fig. 1]. He may now for a moment place the opaque disk in front of his right eye, at the same time placing the double prism (each 6°) before the left eye. A horizontal arrow, head to left, having been drawn on a cardboard, he looks through the double prism, and sees two horizontal, hence parallel, arrows. On removing the opaque disk from the right side of the trial frame, a third arrow appears between the other two, but not parallel with them—it

FIGURE 2.

is oblique down and to the patient's left. On removing the double prism two arrows are at once readily seen, the one crossing the other, as in Fig. 8 [Fig. 2]. In a moment the two arrows begin to shut and open like the blades of a pair of scissors, and finally they are merged indefinitely into one."

I commenced the experiment convinced that artificial astigmatism would produce the same image changes which result from natural astigmatism; and what convinced me was that my 3 D. artificial hypermetropic astigmatism was thoroughly corrected by a + 3 D. cylinder, axis coinciding with the meridian of unaltered curvature. The above experiment seems to be convincing. I have other reasons for believing in the obliquity of images, and will give some of them in words I recently used in the *Journal:*

"Let Dr. Hotz take any case of astigmatism of more than 3 D., with the meridians of greatest curvature either vertical, horizontal, or oblique; and if the patient has ordinary intelligence, he can soon satisfy himself that astigmatism is not only capable of blurring, but also of distorting an object. One eye should be excluded, while the patient is asked to look at a rectangular card two by four inches held vertically immediately in front at the reading distance. As the card is revolved on a pin piercing its center, the patient should be asked its shape when at three definite points. When the long sides of the card are parallel with the meridian of greatest curvature, the patient will say that it is a rectangle; when these sides form an angle of 45° with the meridian of greatest curvature, the answer will come quickly that it is a parallelogram; again, when these sides are brought to right angles with the meridian of greatest curvature, the card again is seen as a rectangle. But possibly Dr. Hotz is ready to say that these statements, as to the distortion of the object, prove nothing as to the distortion of the retinal image. Let us see. The law of projection (direction) is supreme in monocular vision, therefore the lower border of the retinal image must be in the same plane with the upper border of the card, and so on for all the borders of card and image; and these planes must all cut the nodal point. Then, in obedience to this law, the image must be distorted when the object appears to be.

"Only one other argument as to the distortion of the retinal image in an astigmatic eye, when the object is held so that its outlines are oblique to the principal meridians. All will agree that the meridian of least curvature is the line of union of the bases of the prismatic arrangement of the astigmatic cornea, and that all prisms refract light toward the base. Let us then take the right eye of a case of astigmatism with the meridian of least curvature at 135°. A horizontal line held before this eye will send its light from its entire length into the eye, but, for the convenience of study, we will consider only the axial rays coming from the two extremities. The ray from the left end of the line strikes above the meridian of least curvature, and must be bent toward it, its subsequent course in the eye necessarily being down and out; the axial ray from the right end of the line strikes below the meridian of least curvature, and must be bent toward it, the course of this ray after refraction being up and in. Thus it is easily shown that the image of this horizontal line must be inclined down and to the right. Because of this inclination of the image the line itself seems inclined to the same extent, and in the same direction. This is one law of physiologic optics.

"The distortion of retinal images in monocular vision is settled by the law of direction; the rotation of the eyes by the oblique muscles, in oblique astigmatism, is compelled by the more powerful law of corresponding retinal points."

Dr. Hotz made the following quotation from one of my papers: "In oblique astigmatism, be the obliquity much or little, it is a physical impossibility for the horizontal object and its retinal image to occupy the same plane. The same is true of all objects not in a plane with one or the other of the two principal meridians." Forgetting that the closing sentence of the above quotation had been made, the Doctor informs me and your other readers that "the objects in nature are not all horizontal arrows, but present also vertical and oblique outlines, . . . unfortunately for Dr. Savage's theory."

The fact that when oblique astigmatic eyes attempt to fuse images of a horizontal line, the images of a vertical line harmonize less, which Dr. Hotz thinks unfortunate for my theory, is favorable to my teaching. In an editorial in the *Ophthalmic Record*, referring to Dr. Wilson's criticism, as published in the *Archives of Ophthalmology*, I conceded that the same eyes could fuse images of either horizontal or vertical lines when they existed alone; for example, the meridians of greatest curvature diverging above, the superior obliques would cause the fusion of the images of a horizontal line, and the inferior obliques would fuse the images of a vertical line. In the same editorial I taught that when both horizontal and vertical lines are viewed the eyes attempt the fusion of the horizontal lines only; but was unable then, and am unable now, to give any reason for this. I only know it to be a fact. My knowledge of the fact rests on these observations, which may be repeated by any one: In a case of 3 D. astigmatism with meridian of greatest curvature at 135° for the right eye and 45° for the left eye, if a rectangle be looked at by the right eye alone, it will be seen as a parallelogram leaning down and to the left; by the left eye alone, a parallelogram leaning down and to the right; with the two eyes together, it will be seen as a trapezoid with the longer side above. By action of the superior obliques the upper borders of images (lower border of object) are completely fused, while at the same moment all of the lower border of right image, except its inner extremity, is fused with a corresponding portion of the same border of the left image. The parts of the lower borders of the two images not fused are directly continuous with the fused portion, hence the greater length of the upper border of the object. Of the two diverging borders, the right one is seen by the right eye, and the left one by the left eye.

If the meridians of greatest curvature had converged above, the action of the inferior obliques in binocular vision would have converted the rectangle into a trapezoid with the longer side below. As already stated, this preference for fusing horizontal lines is distinctly shown in the higher degrees (3 D. or more) of natural oblique astigmatism. It is also distinctly shown in similar degrees of artificial astigmatism. The chief purpose of the existence of the recti and the *oblique* muscles is the fusion of images in binocular vision.

As to Dr. Hotz's experiment with his +10 ⌒ +2 cylinder, I have this to say: His slit in the metal screen was entirely too short (one inch) to be so far removed (several feet) from the surface representing the cornea. Necessarily this slit at such a distance would throw a very small image on the ground glass four inches behind the lens, and thus make it very difficult to detect the slight leaning (less than 2°) of the borders, caused by the weak cylinder used. A slit several inches long and only a few feet away from the lens, would have thrown a much longer image on the ground glass, so that the very slight change in the direction of the image borders could have been easily detected.

Finally, allow me to try to break in pieces the keystone of his argumental arch—viz., the clinical test to which he put my theory. The case reported was one of mixed astigmatism, and the cylinder given the right eye was probably a —3 D., and that for the left eye a —2 D. The meridian of greatest curvature in O. D. was at 115°; in O. S., at 65°. (These meridians diverged above. The image of a rectangle would have been distorted down and in by each eye, and in binocular vision these leaning parallelogram images would have been fused, so that the patient would have seen a trapezoid, long side above.) The correcting cylinders were given, and metamorphopsia was observed at once by the patient; but he does not give the character of the changed vision. Without the correcting lenses on, he resorted to a test—the double prism—which he states that I had advised, and he found all three lines parallel.

My first stroke at this "keystone" will be with the statement that I have never resorted to this test by the double prisms in uncorrected natural oblique astigmatism, nor have I ever advised it. I would expect the lines to be parallel, for the obliques from habit would so rotate the two eyes as to make the lines parallel. If he had used the double prism test on his patient, while wearing her spectacles and still troubled with the metamorphopsia, he would have found want of parallelism of the middle lines with the two other lines—it would have inclined down and toward the corresponding side. The same test applied after the disappearance of the metamorphopsia, the spectacles being on, would show parallelism of the lines; but removing the lenses at this time, the test would show the middle line leaning down and toward the opposite side. The explanation of all this is easy:

The double prism test in oblique artificial astigmatism (this I did advise) will always show the dipping of the middle line, because the habit of rotation by the obliques has not been established. In Dr. Hotz's case of mixed oblique astigmatism the superior obliques had been always in the habit of rotating the eyes, and this habit reasserted itself when the eyes were under the double prism test, as may always be expected, and the lines were parallel. If the metamorphopsia has disappeared under the wearing of the lenses, the double prism test applied to the naked eyes will show the middle line dipping down and toward the opposite side, for the habit of rotation has been broken. There never was, there never will be, a time in this case when, with the naked eyes, there was not metamorphopsia of that kind which would have made a rectangle appear as a trapezoid, the longer side above. To this form of metamorphopsia the patient had always been accustomed, and therefore was not worried about it. The form of metamorphopsia with the lenses, when they were first given, was a new kind —the trapezoid had its long side below, necessarily—though the Doctor did not tell so much. Being new to the patient, it was naturally annoying. An explanation of this new metamorphopsia is easy: While carrying the patient through the examination for the lenses, he, of course, excluded one eye. The uncovered eye naturally rolled into the position of rest of all the ocular muscles, and the axis of the cylinder for that eye was located. Similarly the cylinder was given the other eye. In binocular vision the old habit of rotation by the superior obliques was reasserted, and there was a consequent loss of coincidence of the axes of the cylinders and the meridians of least curvature (the cylinders were concave), the cylinder axes being thrown about 3° in the arcs of distortion for the inferior obliques. In this case the metamorphopsia could disappear only by the superior obliques giving up work which the inferiors must take on. Without the lenses the superior obliques have been forced to converge the naturally vertical meridians; with the lenses on the inferior obliques must parallel these meridians. Usually this change is quickly accomplished in cases like this one. Dr. Hotz will not deny that the cylinders given changed the direction of the images of vertical and horizontal lines. To my mind it is clear that the leaning of images, caused by the lenses, was equal in extent, but opposite in direction, to that produced by the astigmatic cornea. The lenses have only rectangled the images of the rectangular figure. If in these cases the oblique muscles would only allow the cylinder axes and the meridians of best curvature to remain coincident in binocular vision, there would be no such thing as metamorphopsia ever complained of. It is never observed by patients having astigmatism equal in the two eyes and the best meridians parallel, though they may be oblique. When the meridians of greatest curvature converge above the use of correcting cylinders is always attended by metamorphopsia, which is slower to disappear than in cases like Dr. Hotz's.

Dr. Hotz's closing paragraph, if true, would wipe out all that I have ever written about oblique astigmatism and the oblique muscles. This is his language: "It is therefore evident that neither experiments nor clinical observations nor the laws of physiological optics sustain the doctrine of the obliquity of the retinal images and the necessity of any action of the oblique muscles in oblique astigmatism."

In another part of this reply I have shown conclusively that both experiment and clinical observation showed my teaching to be correct, so that two of his three witnesses against my views have been made to testify for them. It is even easier to capture his third witness (physiological optics), and thus make the trio give evidence the very opposite to that which he intended they should give. Without doing violence to the laws of physiological optics, I may state that every point of an astigmatic cornea has two radii of curvature: one the radius of spherical curvature, the other the radius of cylindrical curvature.* In the horizontal meridian of a vertical astigmatism these two sets of radii are in the same plane, hence the rays of light entering this eye in the horizontal meridian would be in the same plane after refraction as before. Above or below the horizontal meridian, and out or in from the vertical meridian, there is

*There is but one radius, the resultant of the other two. This radius is not that of a spherical or a cylindrical surface, but of a sphero-toric surface.

not a corneal point that would give us these two radii in the same plane; the radius of spherical curvature would go to the center of the sphere, while the radius of cylindrical curvature would necessarily be in a horizontal plane. Both of these radii will be directed to the plane of the vertical meridian, but they diverge as they go. A ray of light striking such a point must undergo a double refraction (a resultant refraction). If the corneal point is thus related to the horizontal and vertical meridians, the ray of light passing through it must be deflected toward each of the two radii; therefore, the refracted ray can no longer occupy any plane in common with the incident ray.

Allowing the retina to remain in its normal position, let us revolve the astigmatic cornea discussed above, so that the astigmatism shall be oblique at an angle of 45°. In doing this, we have not altered the relationship of the two sets of radii. Those that were in the same plane before are so now; those that diverged before diverge still. Let us conceive it to be the right cornea and that the meridian of least curvature now stands at 45°. The meridian that was at 45° when the astigmatism was vertical stands at 180° when the astigmatism is oblique at 45°. What happens now to an axial ray in the horizontal plane? We will take three of these rays and follow them as they make their way to the retina. One ray is from the middle of a horizontal line (arrow, if you please), one is from one end of the line, and the other is from the other end. These rays must converge toward that part of the cornea in front of the pupillary space. They come to the eye in the same plane and strike the horizontal meridian of the cornea. The point of fixation is the center of the line; therefore the middle of these three rays strikes the center of the cornea vertically, and coincides with both the radius of spherical and the radius of cylindrical curvature for that point, hence passes through the cornea without being refracted at all, and impinges on the retina's horizontal meridian. The ray from the right end of the line strikes the right side of the cornea at a point in the horizontal meridian, the two radii of which diverge, the radius of spherical curvature being in the horizontal plane, the radius of cylindrical curvature pointing down, as well as toward the plane of the meridians of least curvature. It is clear that this ray must undergo a double (resultant) refraction. Striking the cornea to the temporal side of the radius of spherical curvature, it is so refracted as to converge less toward the middle axial ray (in this it is aided by the cylindrical curvature), and being incident to the radius of cylindrical curvature on its lower side, it must be refracted down also. Following its subsequent course, we find it impinging on the retina below the horizontal meridian, to the nasal side of the vertical meridian. The ray from the left end of the line, coming to the cornea in a plane with the other two, strikes the cornea on the nasal side of its center and in the horizontal meridian, at a point where the two radii diverge, the radius of spherical curvature being in the horizontal plane and the radius of cylindrical curvature pointing up and toward the plane of the meridian of least curvature. Striking the cornea on the nasal side of the radius of the sphere, this ray is made to converge less toward the middle ray than before refraction; striking the cornea on the upper side of the radius of cylindrical curvature, it is also refracted upward. Following this ray to the retina, we find it impinging above the horizontal and on the temporal side of the vertical meridian. A line drawn through these three points of impingement will locate the image of the line (arrow) looked at. It is inclined in obedience to the plain law of refraction that a ray of light in passing from a rarer into a denser medium must be refracted toward the perpendicular at the point of impingement.

There is one other objection which Dr. Hotz brought forward—viz., while a concave cylinder held obliquely in front of an eye at some distance will make horizontal and vertical lines appear inclined toward its axis, this inclination grows less and less as the eye is approached, and, as he thinks, disappears entirely when the cylinder is brought into contact with the cornea.

This is all easily explained. Take again the three axial rays in a horizontal plane. Striking the horizontal portion of the oblique cylinder, the middle ray passes through unrefracted and continues in the same plane, while one of the outer rays is made to deviate downward, and the other upward. For convenience of study we will say that the deviation of each ray is 2° from the horizontal plane. This deviation continues the same until the retina is reached, regardless of whether this distance is one meter or 25 mm. In obedience to the law of direction, the horizontal line is made to appear to incline more when the cylinder is held one meter from the eye than when it is held 50 cm. away. In obedience to the same law, the line appears less and less inclined as the oblique cylinder is made to approach still nearer the eye, but even when brought into contact with the spherical cornea, its inclination does not and cannot disappear entirely, though often one may not be able to perceive that there is still an inclination. This apparent change in the direction of a line, viewed through a concave cylinder held obliquely as it is moved from arm's length to the eye, could not be explained if Helmholtz's law of direction were true. If the axial ray were the line of direction, the apparent obliquity of a horizontal line would be the same, whether the cylinder causing the phenomenon were held at arm's length or in contact with the eye, for the reason that, after the axial rays are deflected, some above and some below the horizontal plane, they pursue a straight course (except for spherical refraction) to the retina, whether it be far away or near by. These rays prolonged, according to Helmholtz, would locate the source of the light, and necessarily would give it the same apparent inclination for all distances at which the cylindrical surface might be held from the eye. Not so with that law of direction which says that all lines of direction are radii of retinal curvature prolonged. This law makes it necessary for the line to appear to incline more when the cylinder is held far away from, and less when it is brought close to, the eye.

CHAPTER IV.

OBLIQUITY OF RETINAL IMAGES IN OBLIQUE ASTIGMATISM AS SHOWN BY PHOTOGRAPHY.

Since the first edition of this book was brought out, photography has been called in to give evidence as to the teachings found in Chapters I. and II. of that edition (I. and V. of this edition). Dr. Harold Wilson asked the camera to prove that the teachings were false, by showing that an astigmatic lens did not distort images on the sensitive plate. He took several photographs of a church spire: one with a nonastigmatic lens; one with an astigmatic lens, axis at 90°; two with axis at 45°; and two with axis at 135°. From these several photographs half-tone cuts were made, which were used by him to illustrate his paper, which was published in the *Journal of Ophthalmology, Otology, and Laryngology*, July, 1895. He claimed that these photographs showed conclusively that an astigmatic cornea does not distort retinal images; and therefore, the teaching that, in oblique astigmatism, the oblique muscles must act harmoniously and symmetrically had no foundation in fact. Sometimes in court a witness, called to give evidence favoring one side, states facts that are clearly in favor of the other side of the case. So it was with Dr. Wilson's camera: the cause that he wished to hurt he helped. In his first two photographs the axis of the spire and the cornice at the base were at right angles, the only difference between them being in distinctness of outline. He expected the reader to believe with him that the same was true of the remaining pictures. These speak for themselves, each one saying that the axis of its spire is not at right angles with the cornice at its base. In each, these lines had been distorted from the axis of the cylindrical lens (toward the meridian of greatest curvature). This is just what we had shown before, independent of the aid of the camera. It would be interesting to reproduce Dr. Wilson's cuts, but we did not think in time to ask him for the privilege of using them. We will present, however, half-tone cuts showing exactly what his pictures distinctly set forth. These cuts were made from photographs of a rectangle taken by Dr. Lowry, at our suggestion, and under the conditions observed by Dr. Wilson. We reproduce not only the cuts, but also the words used by Dr. Lowry in a short paper published in the *Ophthalmic Record*, August, 1895:

"It has often been noted that the camera obscura is very strikingly similar, in its mechanism, to the human eye. In this simple optical instrument we have a mechanical eye, so far as refraction is concerned. If we compare to the eye the component parts of the photographic camera, which is merely a camera obscura with a device for receiving the image on a sensitized plate, we find the refractive media of the former correspond to the photographic lens; the iris, to the stop; the accommodation, to the focusing apparatus; and the retina, to the ground glass. Focus the camera properly, and we have the emmetropic eye. By placing a concave cylindrical lens, axis at 90°, in apposition to the photographic lens, we have simple hypermetropic astigmatism according to the rule. If we place the axis at 180°, we have simple hypermetropic astigmatism against the rule. If we place the axis anywhere between the vertical and horizontal, we get oblique astigmatism. Whether or not the image will be oblique on the ground glass will be seen later.

"To illustrate these points, I have made the accompanying photographs with a rapid rectilinear lens, used in the the Rochester Optical Company's 5x7 midget camera. The camera was not moved or changed in any way for the first five photographs. Fig. 6 was made at another time. The rectangle was made mathematically accurate on a piece of cardboard 24x30. The lines one inch wide are prolonged beyond the rectangle to show more clearly the obliquity that may be produced by the cylinders, obliquely placed. The watch is used as a plumb, and is seen in the same position in all. The photographs are not inverted as the images would be on the ground glass or the retina.

"In Fig. 1, no cylindrical lens is used, and we get a perfect rectangle, sharp and distinct in its outline, as would be seen by an emmetropic eye.

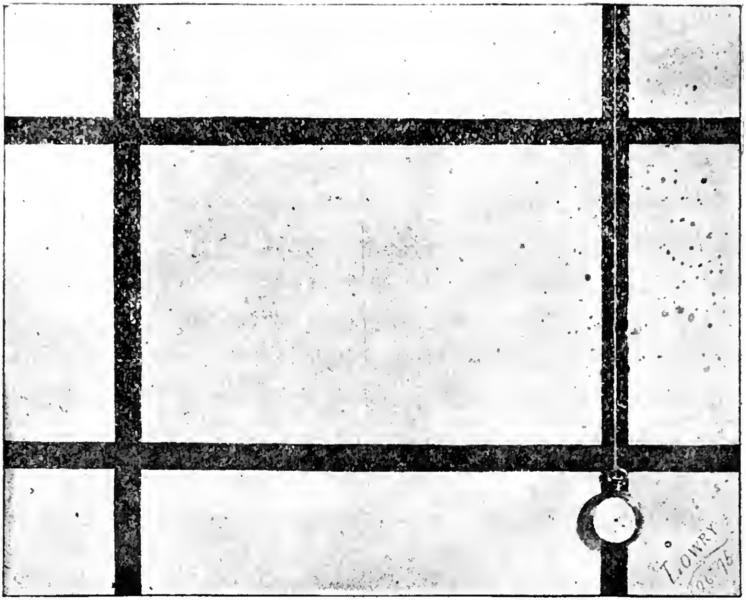
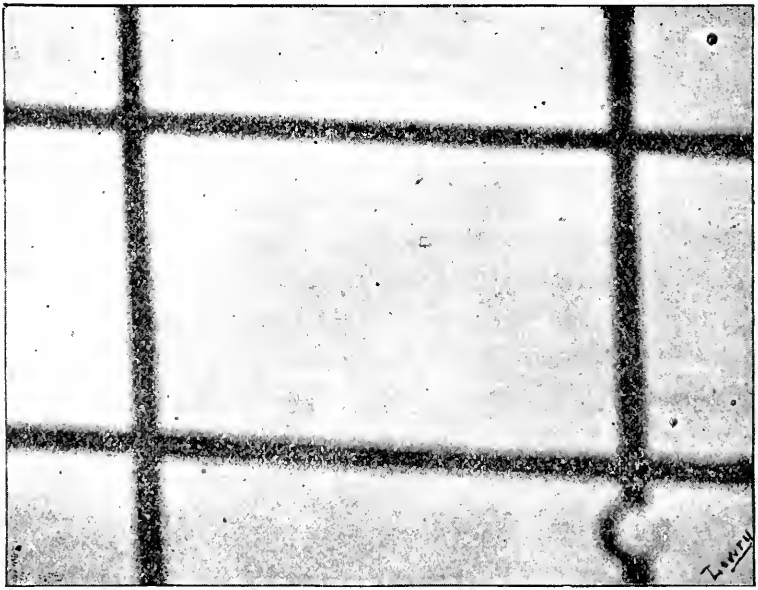


FIGURE I.



(84)

FIGURE 2.

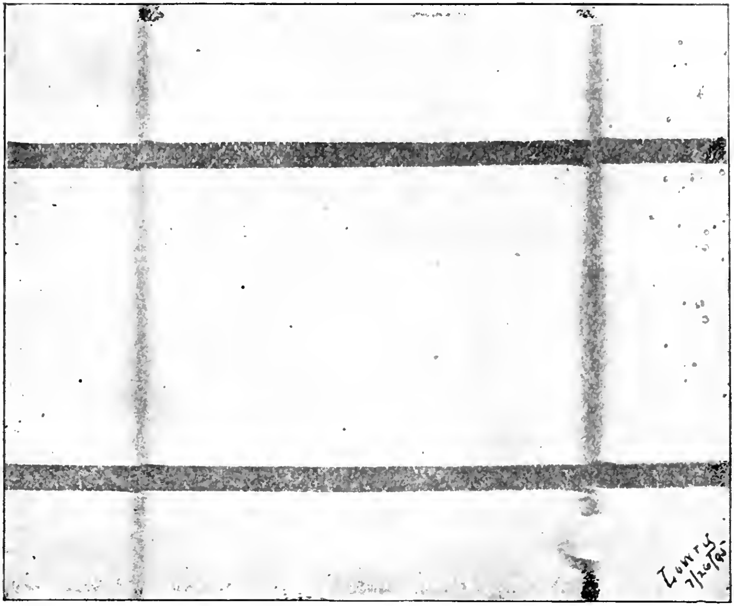


FIGURE 3.

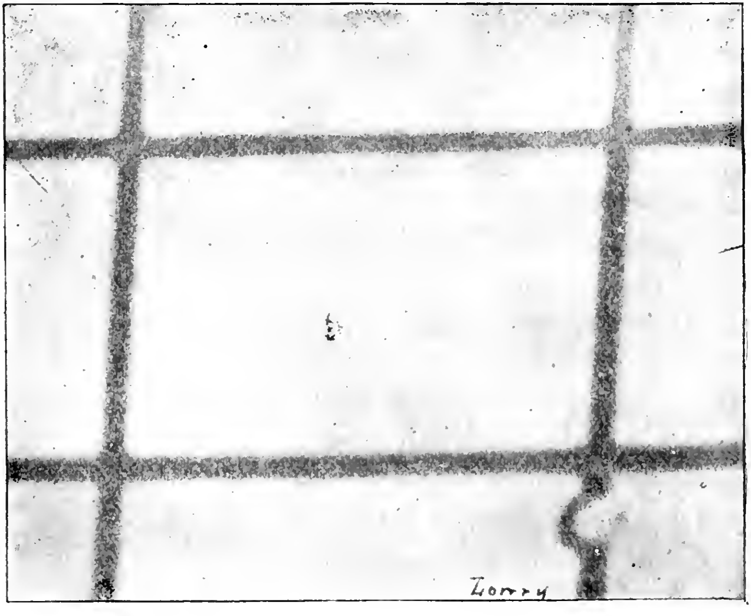


FIGURE 4.

"In making Fig. 2, a —3 D. cylindrical lens is placed just in front of, and in apposition to, the photographic lens, with its axis at 45°. A +1.50 D. spherical lens is used with the cylinder in order to give the middle of the focal interval without changing the camera. In this the vertical and horizontal lines are equally indistinct. The vertical lines deviate to the left at the top, and to the right at the bottom, while the horizontal lines are depressed at the right and elevated at the left. The plumb shows that the card is in just the same position as in Fig. 1, and the camera has not been moved from its original position. This picture is clearly a nonrectangular parallelogram.

"If the axis of the cylinder be changed to 90°, we get Fig. 3, which represents simple vertical hypermetropic astigmatism. This is made without the +1.50 D. sphere, and without the camera being changed in the least from its position in Figs. 1 and 2. The meridian of greatest curvature here is at 90°, with the least at 180°. It is a perfect rectangle with its horizontal lines sharply cut and the vertical very indistinct.

"Now if we place the axis of the cylinder at 135°, again adding the +1.50 D. sphere, a nonrectangular parallelogram is formed with its sides deviating in the opposite direction to those in Fig. 2. This is shown in Fig. 4. Every part is equally indistinct, and nowhere are the lines at right angles as in the original.

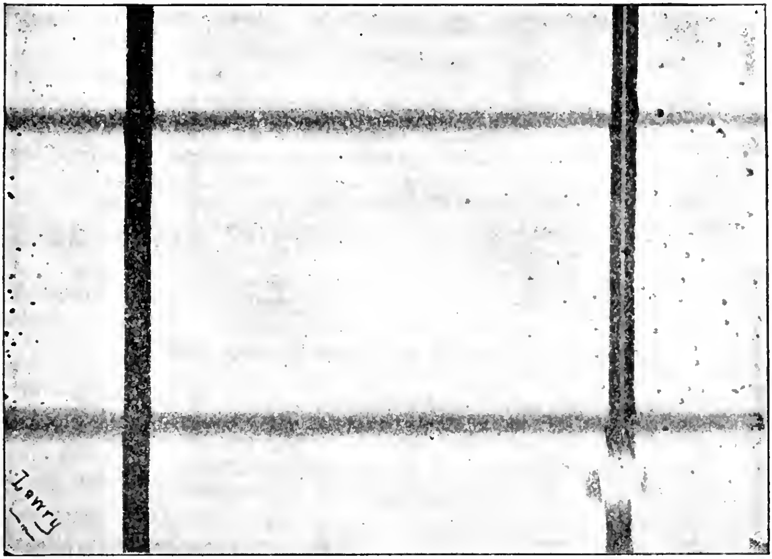


FIGURE 5.

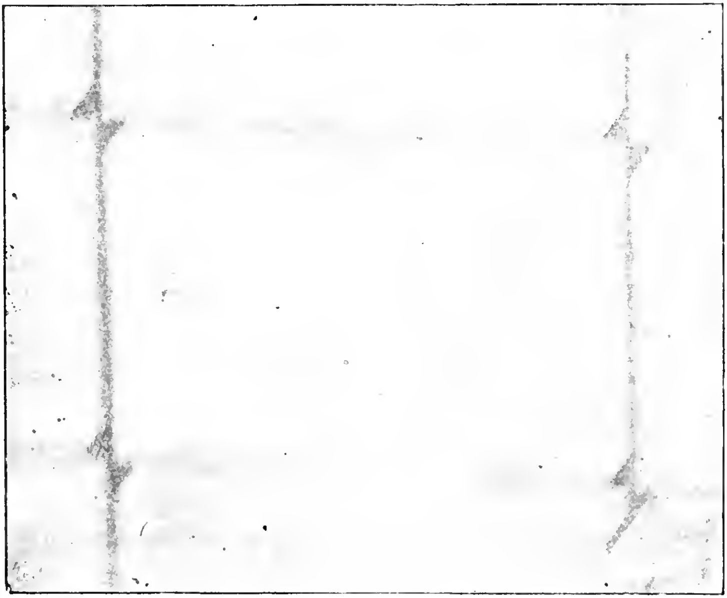


FIGURE 6.

"By placing the axis of the cylinder at 180°, without the +1.50 D. sphere, we produce simple hypermetropic horizontal astigmatism, the effect of which is illustrated in Fig. 5. Here we have the meridian of greatest curvature at 180°, and the least at 90°. We obtain a perfect rectangle, with its vertical lines clear and its horizontal very indistinct, in contradistinction to Fig. 3.

"Fig. 6 is the same as Fig. 2 without the +1.50 D. sphere to give the focal interval, nor is the camera refocused to give it. This photograph was made at a different time, and the camera was not in exactly the same position as for the other five. An eye with the meridian of greatest curvature at 45° and 3 D. of simple hypermetropic astigmatism, would see the object as shown in this figure, if, under the influence of a mydriatic, or in old age, it was relieved of all ciliary action. The rhomboidal figures are seen very clearly here at the angles and on the watch.

"It is very evident that if we had 3 D. of hypermetropic astigmatism in each eye, with their meridians of greatest curvature parallel at 45°, each eye would see the object as seen in Fig. 2; for the rays of light from each point of the object would strike corresponding points of each retina, and the two images would be superimposed, giving, in binocular vision, but one image, distorted as shown in Fig. 2. The person, always having been accustomed to seeing vertical and horizontal objects deviating from their normal position, would suffer no inconvenience from the error other than ciliary strain brought about by an attempt to place the image at the middle of the focal interval in order to get the most distinct image of all its parts.

"Many of the headaches and so-called neuralgias that are complained of by school children, young and middle-aged people, who use their eyes for close work (such as reading, sewing, etc.) are due to this strain, and can be corrected by placing before their eyes the proper cylinders with their axes at the proper angle, which will at the same time correct the obliquity of the image. As mentioned previously, in old age, when there is want of accommodation, or under the influence of a mydriatic, this strain is relieved, but the image is not made more distinct. That oblique astigmatics do really see objects distorted is proved by the fact that some of the noted painters, suffering from uncorrected astigmatism, in placing on canvas what should be vertical, so far deviated from that direction as to mar their otherwise fine paintings.

"The same ciliary strain is noticed in vertical and horizontal astigmatics, and for the same reason. It should be stated, however, that there is no ciliary strain in myopic astigmatism for distance, as any effort on the part of this muscle would tend to make vision worse instead of better, and any strain is an attempt in some way at an improvement of the image of an object.

"Suppose one of the meridians of greatest curvature to be at 45°, and the other at 135°, one image would be seen as in Fig. 2, and the other as in Fig. 4; in obedience to the law of corresponding retinal points, we would have these two figures superimposed, forming a trapezoid. If the meridians diverged above, we would have the long side above, and the short side below. In this form of astigmatism we would not only have a ciliary strain, but the superior obliques would make an attempt to bring the harmonizing parts of the two retinæ under the dissimilar images in order to have a single image. If the meridians converged above, the short side of the trapezoid would be above, and the long side below. This fusion of dissimilar parallelograms into a trapezoid, long side below, would be effected by the inferior obliques. Dr. Savage has shown this very clearly in his paper read at the Edinburgh Congress.

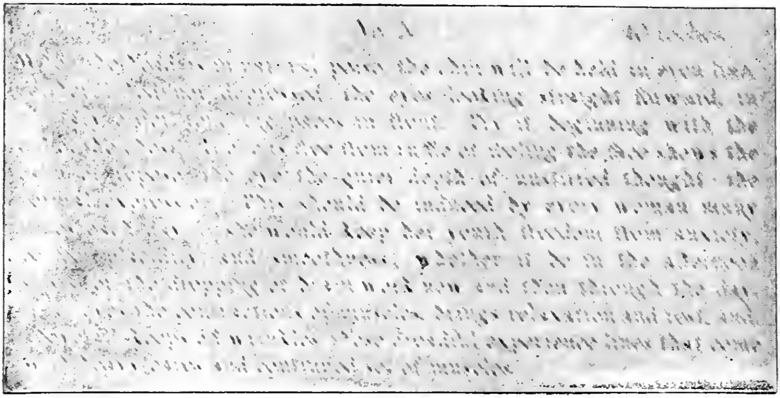
"But the bone of contention has been principally the question of the deviation or the nondeviation of the image on the retina in oblique astigmatism. Others have proved it by the laws of optics, by clinical experience, and by logical reasoning; and it seems to me that my photographic demonstrations have added very conclusive evidence to Dr. Savage's theory that, in oblique astigmatism, the retinal images of vertical and horizontal objects deviate from their normal direction."

Not knowing that either Dr. Wilson or Dr. Lowry were at work with the camera (the one to disprove, the other to prove, what we have taught on the subject of oblique astigmatism and the oblique muscles), Dr. Perry, of Oneida, N. Y., undertook some experiments with his camera with neither object in view, but wholly for another purpose. With only one aim in view primarily, he accomplished two things finally. The unexpected result which he attained was the confirmation by photography of our views on the distortion of retinal images by oblique astigmatism. His paper, illustrated by his photographs of Jaeger print, was published in the *Ophthalmic Record*, August, 1895. We quote from this paper the following:

"When photographs 7 and 8 [4 and 5 in his original publication] were taken, one end of the line was found to be higher than the other, showing the screwlike direction of the rays referred to by Dr. Harold Wilson, of Detroit, in his article in the *Archives of Ophthalmology*, July, 1894.

"When the two cards (one representing astigmatism of 45°, and the other one of 135°) are put in a stereoscope in such a way that one card is seen with the right eye and the other with the left, it is found that one end of each must be raised from one-eighth to one-fourth of an inch to make the two images blend. After the blending, the ends may be carried still higher or dropped back, so as to be nearly parallel without separating the images. This tends to confirm the theory of Dr. Savage that the images in symmetrical oblique astigmatism are blended by the rolling of the eyeballs on their antero-posterior axes by the action of the oblique muscles. The two cards pivoted to a third, which fits an ordinary stereoscope and arranged to move synchronously, make a simple and inexpensive apparatus for exercise of the oblique muscles.

"The fact noted by Dr. Wilson, that in oblique astigma-

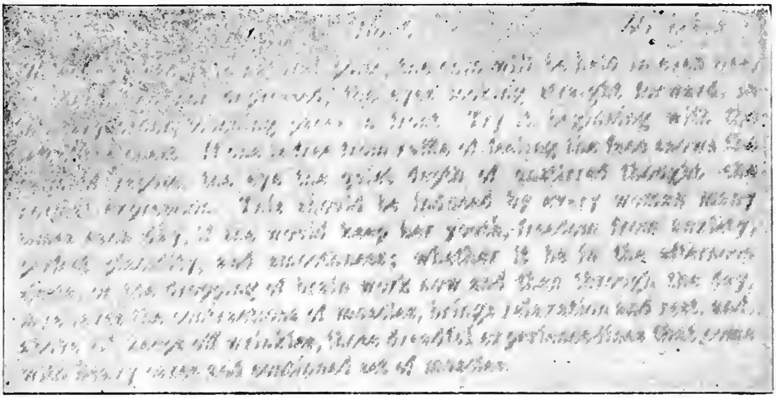


NO. 7.

tism the projection of the vertical line is turned in a direction contrary to the horizontal, seems not to be a practical objection to the theory of Dr. Savage, as in reading we see only horizontal lines—that is, we see whole words, however long, without seeing the line above or below."

In commenting on the last paragraph above quoted, it may be said that Dr. Wilson was not the first to point out that, in oblique astigmatism, "the vertical line is turned in a direction contrary to the horizontal." In 1891 we taught that all lines not parallel with, or at right angles to, the meridian of greatest curvature are deflected toward it, hence the vertical in a direction contrary to the horizontal.

Still pursuing his studies of the distortion of the retinal



NO. 8.

images by oblique astigmatism, Dr. Perry was able to have another ingenious half-tone cut made, which he used to illustrate another paper, which was published in the *Ophthalmic Record*, November, 1895. This paper is so full of both truth and interest that we reproduce it here in full:

"The experiments described below were made to determine whether adjustment for binocular vision, in symmetrical oblique astigmatism, involves a movement of rotation on the visual axes.

"It is intended to show experimentally: First, that an astigmatic lens or dioptric system so distorts the visual image as to deflect radial lines on opposite sides of its axis in contrary directions; secondly, that when such images are formed on the retinæ of a pair of symmetrically oblique astigmatic eyes, rotation takes place in the direction required to carry corresponding points of each retina to correlative points in the image.

"Fig. 9 was produced by taking a photograph of the graduated circle with printed words as shown; and then, without moving camera or object, placing a .50 D. cylindrical lens in front of the objective and exposing a second negative, and when the photographs were finished, cutting away the outer circle from the astigmatic print and pasting it over the other in such a way as to make the horizontal and vertical lines respectively coincide on the two prints. If the cut is held so that the line of the print reading "Astigmatism Oblique 135°" is horizontal, it will be observed that the distortion of the field is such that this particular line is moved along the scale nearly two degrees, while the line which is perpendicular to it is moved an equal distance, but in a contrary direction. This shows what must happen to a retinal image in oblique astigmatism.

"Fig. 10 represents a stereoscopic card to which are cen-

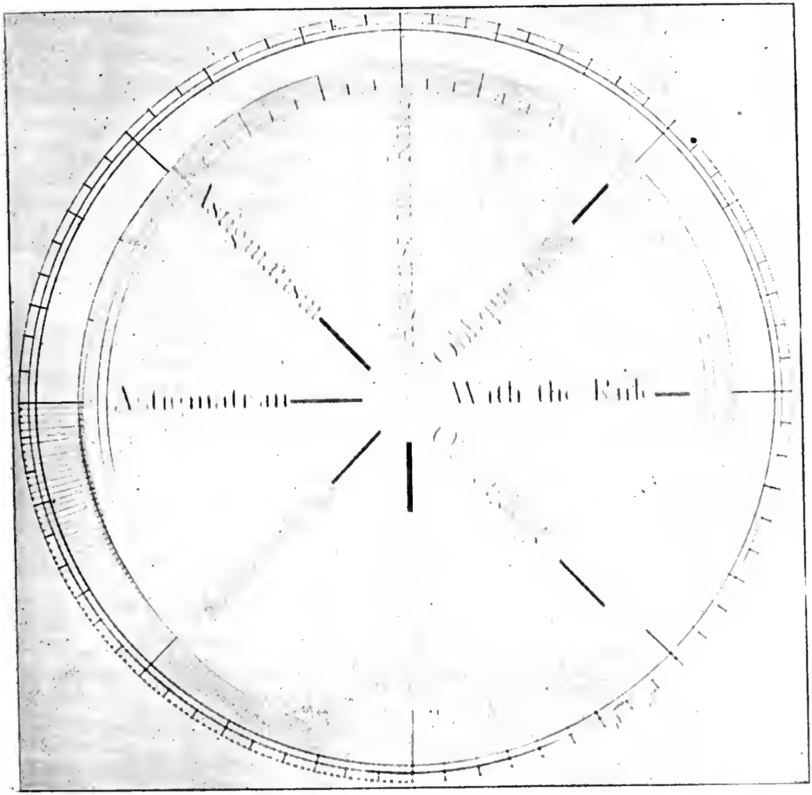


FIGURE 9.

trally pivoted two thin disks, each three inches in diameter, their centers being three inches apart in a horizontal line."

"These disks are mashed together at their point of contact by a single interlocking slot in each.

"The left disk is moved by a lever passing under the right, and is provided with an index, which shows on a graduated scale at the right-hand of the card the number of degrees that each disk is rotated. Having equal diameters, and being geared together, they move synchronously equal

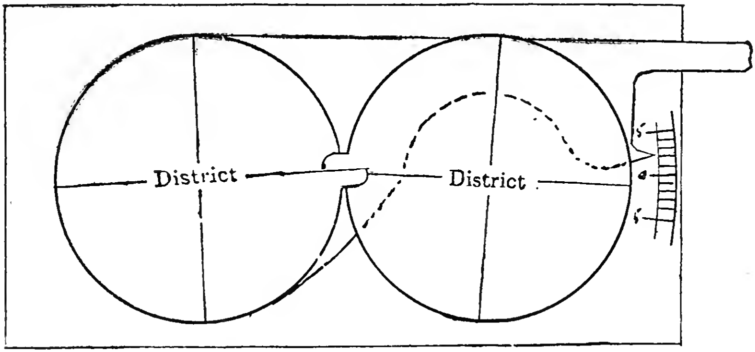


FIGURE 10.

distances, but in opposite directions. Horizontally over the center of each disk is printed a word, and vertically through each of said centers is drawn a line.

"When this apparatus is seen in a stereoscope and the disks are rotated by moving the lever, the two words will remain blended while each disk moves through an arc of about 5° (and much more in some subjects); and if attention is given to the perpendicular lines, they will appear as a single line during the rotation of about the same arc. If used with due care, this instrument gives a practically accurate measurement not only of the relative, but of the absolute, power of rotation in each direction.

"To make the concluding part of the experiment, the card must be immovably secured to the stereoscope, which should be rigidly fixed to a table or stand provided with a chin rest, and while the subject of the experiment is looking at the words, an assistant should, by moving the lever, rotate the disk about 5° back and forth—that is, carry the index about 2½° above, then 2½° below, the point marked 0 on the scale. During this rotation, if the operator observes the ophthalmoscopic erect image of a vessel on the nasal side of the retina, he will see it move downward over the field of the pupil as the upper edges of the disks are rotating outward, and upward when they are rotating inward.

"If the subject of the experiment now gives his attention to the vertical lines, the vessel is seen to move up when the disks are rotating outward, and down when they are rotating inward—that is, in a direction opposite to that seen when the word or horizontal line is observed. If a conjunctival vessel is observed with a microscope under the same conditions, no decided motion can be seen.

"The facts demonstrated by the first of the above-described experiments have been proved in a variety of ways, the result of the demonstration by geometrical optics being unquestionable; but, so far as the writer is informed, the direct observation of the rotary movement of the eyeball under the conditions stated is not on record."

At first our critics intrenched themselves behind the declaration that an astigmatic cornea is incapable of distorting images whose outlines are not parallel with, or at right angles to, the meridian of greatest curvature. They characterized our declaration of this distortion as false. They reasoned that since there is no distortion of images there can be no need for the harmonious symmetric action of the oblique muscles. If they were correct in their concept, their deduction would necessarily be true. We were willing to meet them on their own ill-chosen ground, and either fall in the contest or drive them from the nondistortion fort which they had erected. The result of the contest on this question we leave to the judgment of him who will read carefully the first four chapters of this book. We claim that observation, clinical experience, physiologic optics and photography all agree in establishing the doctrine that an astigmatic cornea distorts the images of all objects whose outlines are not parallel with, or at right angles to, the meridian of greatest curvature. If these images are distorted in opposite directions in the two eyes, then there must be harmonious symmetric action of the oblique muscles in order to harmonize the images, so as to give binocular single vision. To believe otherwise, one must deny that *the supreme law of binocular single vision is the law of corresponding retinal points.*

If we have succeeded in establishing the fact that the oblique muscles are called into special action when, in astigmatism, the meridians of greatest curvature converge or diverge above, we have succeeded at the same time in confirming the correctness of our method of exercising weak oblique muscles, as set forth in Chapter V. If what is taught in the first four chapters of this book is true, the teaching of Chapter V. cannot be false.

CHAPTER V.

INSUFFICIENCIES OF THE OBLIQUE MUSCLES AND HOW TO CORRECT THEM.*

IN the *Archives of Ophthalmology*, Vol. XX., No. 1, 1891, I announced my discovery of "Insufficiency of the Oblique Muscles." I closed that paper by saying of the nervous symptoms brought about by this state: "I can see no hope of prevention or cure." On the 17th day of May, 1892, while a patient was before me, whom I had known to be a sufferer from this condition for two years, and to whom I had often said, "There is not now, nor can I see how there ever can be, any relief for this trouble," a thought of the proper means of correction dawned upon me. I at once applied, in this case, the newly thought of principle, and with the most gratifying results. Of this case I shall have more to say before closing this paper.

Before setting forth the treatment I will refer to the condition itself, and the proper means of detecting it. In doing this, since I cannot do better, I quote from my paper published in the *Archives:*

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* Read before the Section of Ophthalmology of the American Medical Association, at Detroit, June, 1892.

"Every ophthalmic surgeon, however skilled in correcting errors of refraction, and in operating for the different known forms of heterophoria, has had cases of eye-strain for which he could do but little. In investigating a few such cases during the last six months, I have found the cause to be a want of equilibrium on the part of the *oblique muscles*. The detection of this condition is easy. I place a double prism (my modification of the Maddox prism) before one eye, the other for the moment being covered, and ask the patient to look at a horizontal line on a card held eighteen inches away. The effect of the double prism (each 6°, bases in), so placed that the axis is vertical, is to make the line appear to be two, each parallel with the other. The other eye is now uncovered, and a third line is seen between the other two, with which it should be perfectly parallel.

"While a change of the position of the axis of the double prism, from the vertical toward the horizontal, will alter the distance between the lines, their direction will be unchanged; hence no loss of parallelism. This fact admits of a little carelessness in the placing of the prism in the trial frames; though the axis should be vertical, so as to give the maximum distance between the two extreme lines.

"If there is a want of harmony on the part of the oblique muscles, this test will show it at once in a want of parallelism of the middle with the two other lines, the right end of the middle line pointing toward the bottom and the left end toward the top line, or *vice versa*, depending on the nature of the individual case.

Fig. 1

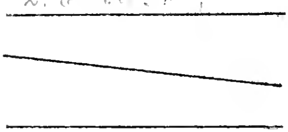


Fig. 3.

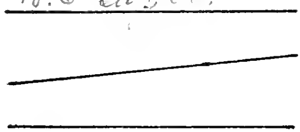


Fig. 2

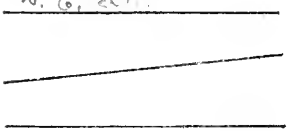


Fig. 4.

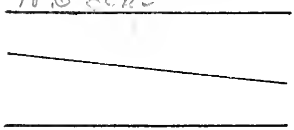
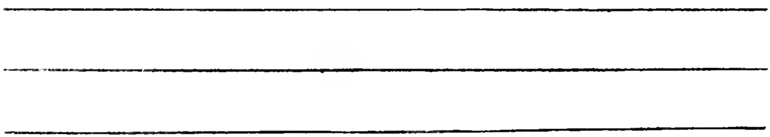


Fig. 5.



"In my investigations, I have always considered the eye before which no prism is held as the one under test. With the double prism before the right eye, the patient is asked about the position and the direction of the middle line. It may be nearer the bottom, thus showing left hyperphoria;

or again, it may extend farther to the right than the other two and not so far to the left, thus showing exophoria; or *vice versa*, showing esophoria.

"If the right ends of the middle and bottom lines converge while the left ends diverge, the superior oblique of the left eye is at once shown to be in a state of underaction. Figure 1 represents such a test of the left eye. Figure 2 shows a test of the left eye when the inferior oblique is the too weak muscle. Figure 3 represents a test of the right eye, the loss of the parallelism between the lines being due to underaction of its superior oblique; and Figure 4, the same condition of the inferior oblique of the right eye. Figure 5 represents a test of both eyes when there is perfect equilibrium of the oblique muscles.

"As is well known, the function of the oblique muscles is to keep the naturally vertical meridians of the two corneas parallel even when not vertical [except in cases of uncorrected oblique astigmatism, as shown in Vol. 1, No. 1, of the *Ophthalmic Record*]. This must be, or a troublesome form of double vision will result. If there is perfect equilibrium of the obliques, this parallelism of the meridians named is maintained without trouble; but if the superior oblique of either eye be too strong for its inferior, or *vice versa*, the parallelism of the vertical meridians is preserved, and double vision is prevented, only by excessive work on the part of the weaker muscles. This condition of the oblique muscles brings on, at longer or shorter intervals, a train of nervous symptoms for which, at present, I can see no hope of prevention or cure."

As can be readily seen, the condition described in the *Archives* was *symmetrical insufficiency of the obliques.* Up to that time I had not seen, nor had I heard of, a case of *non-symmetrical insufficiency of the obliques.*

Dr. Moulton, however, reported such a case in a letter* to the editor of the *Ophthalmic Record.* I had reasoned that such a condition would not give trouble, since the strong muscles would be allowed to overact, thus revolving the two eyes in the same direction, but causing no disturbance of vision. I still believe this reasoning correct except in cases of *corrected* astigmatism. Such a case Dr. Moulton reported, asking for an explanation of the fact that it became necessary for him to rotate his 1.00 D. cylinders from 90° to 100° for each eye, in order that the patient might have comfort, when several examinations under atropia had shown that the axis of each cylinder should be at 90°. My explanation, published in connection with his letter, was that there was insufficiency of the superior oblique of the right eye and of the inferior oblique of the left eye; that these weak muscles, at the times of the several examinations, exerted their full amount of power, and thus kept

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* See *Ophthalmic Record*, Vol. 1, No. 4, 1891.

the best meridians at 90°; that these muscles at other times, because of fatigue, could not exert the necessary amount of power, and thus allowed their stronger opposing muscles (the inferior oblique of right and superior oblique of left) to change these meridians from 90° to 100°. It was at such a time as this that the Doctor learned that the axes of his cylinders should be placed at 100°. Comfort came to, and remained with, his patient as a result of this little procedure. It was good practice, and should be followed in all cases of astigmatism where there is *nonsymmetrical insufficiency of the obliques.*

In *symmetrical insufficiency of the obliques*, the case is very different in both principle and practice. It is for this latter condition that I am now able to point out the remedy.

To illustrate clearly the principle and practice, I will take up for study the case of J. B. M., age thirty-five, whose case I was studying the moment the thought of the cure came to me. Two years ago he came to consult me about a headache that for a long time had troubled him, and which was growing more severe. He had been advised that it was probably due to eye-strain; and, if so, it could be cured by properly adjusted lenses. A preliminary examination showed only a slight error of refraction. This he consented to have corrected, hoping that he would get relief, other means having failed. Under homatropine the following correction was given:

O. D. V. = $\frac{20}{xx}$ with + .25 ⌒ + .25 cyl. ax. 155°.

O. S. V. = $\frac{20}{xx}$ with + .25 ⌒ + .50 cyl. ax. 90°.

It was determined, at the same time, that he had ½° left hyperphoria. It was also determined that he had insufficiency of both right and left superior obliques. He was told that all but the latter could be corrected; that he would get some, but not complete, relief by wearing his sphero-cylindrical lenses, the left ground on a prism of ½° base down; that, at times, the insufficiency of the obliques would give him trouble, for there was nothing that could be done for this condition. I did tell him that if he felt a headache coming on, when engaged in near work, he might cover one eye with a flap, thus doing away with the strain necessary for harmonious action of the muscles of the two eyes. This he tried occasionally, but found it very inconvenient to work with one eye only. His attacks of suffering were greatly lessened in both frequency and severity for some months, as a result of the elimination of some of the factors formerly constituting in part the cause of his suffering.

He wore his spectacles continually; but after awhile his headaches began to return. They grew more frequent and more severe until he became an almost daily sufferer. Not infrequently, on going home from his office, his wife would have to put him to bed like a child. He would occasionally take medicines prescribed by his family physician to relieve the severity of the attack. At intervals, during the whole time, he would consult me. When complaining, I would tell him that I believed that the then active cause was the insufficiency of his superior obliques; and that I was powerless to do more than I had already advised.

A few months ago I made a second examination of his eyes under the influence of homatropine, but only to find that the result of my former examination was correct. I did not have to urge him to wear his glasses, because he had learned that he was more comfortable with than without them.

On the 13th of May, 1892, he came to me and said that I must do something for him; that he must have relief. Reminding him that I had twice investigated his eyes and each time had found the same conditions and had corrected all that was correctable, I told him I was willing to try again; but that I was as unable to correct the insufficiency of his obliques as I ever was. In the course of this conversation, I told him that, if he had but one eye, he would not be a sufferer. Deciding that it would be four days before he could return for another examination, he went away. On the 17th, at the hour appointed, he came; and, without hope of finding an additional means of relief, I undertook the investigation again. The results of former examinations, as to lenses, were confirmed.

My study of the recti muscles resulted as formerly in finding a left hyperphoria of $\frac{1}{2}^\circ$. With the remark, "We will now look into that incorrectable condition," I began to investigate the obliques. Placing the 6° double prism before his right eye, the left eye (the one under test) showed the middle line dipping unmistakably to the right, as in Figure 1, thus showing insufficiency of the left superior oblique. Transferring the double prism to the left eye, the right eye showed the middle line dipping to the left, as in Figure 3, thus showing insufficiency of the right superior oblique. Having stated again that nothing more could be done for him, in the next moment the thought occurred to me that, if a cylinder was placed before the eye in such a way as to make the line incline still more in the same direction, on removing the double prism the weak obliques would have to act more than usual in binocular vision. I reasoned that this overaction, being in the nature of gymnastic exercise, if conducted properly, must develop the weak muscles, and thus be a source of relief to the patient. Leaving the double prism in front of the right eye, I placed a + 2.00 cylinder before his left. Revolving it so as to bring its axis to 135°, the middle line was seen to dip very much more to the right. I then turned the axis back to 90°, when the dipping was the same as when no cylinder was on. Turning the axis of this cylinder to 45°, the middle line was made parallel with the other two (this little procedure of placing the axis of a cylinder obliquely, first in one direction, then in the other, and watching the effect on the middle line, will establish or disprove the correctness of the diagnosis). The diagnosis made and positively confirmed, I at once commenced the gymnastic exercise by placing a + 2.00 cylinder before each eye, the axis of the right at 70° and the axis of the left at 110°. The patient was asked to fix his vision on a light twenty feet distant (the double prism had been removed). In three minutes the axis of the right cylinder was turned to 60° and that of the left to 120°; three minutes later the axis of right was placed at 50° and that of left at 130°; and again in three minutes the axes were changed, the right to 45° and the left to 135°. With each turning there was additional demand made on the superior obliques, the maximum being reached when the axes were respectively at 45° and 135°. With each turn the patient could feel additional strain. The cylinders were allowed to remain in this position of maximum effect three minutes, when they were removed and the double prism test was applied. There was now the slightest, if any, dipping of the middle line. Both patient and practitioner felt encouraged. He has returned daily for the *exercise*, which has been conducted every time in the manner above described.

On the day after the first *exercise* he resumed his office work, which requires almost continuous near use of his eyes, and has been absolutely comfortable up to this time (the end of the eleventh day), and not one dose of medicine has been taken. For the last three days, before beginning the *exercise*, the test, when applied to either eye, showed but little want of parallelism of the lines. His improvement has been rapid and remarkable.

I have now under the exercise treatment a little girl, age fifteen years, whose trouble is insufficiency of the inferior obliques. The dipping of the middle line is to the left in the left eye, and to the right in the right eye, just the contrary of what was found in the other case.

The *exercise* in her case is carried on by revolving spasmodically the axis of the right cylinder from 90° to 135° and that of the left from 90° to 45°, the reverse of the plan in the first case. She does not bear the exercise so well as the first patient, but her improvement in five days is noticeable.

My records for the past two years show a number of cases of *symmetrical insufficiency of the obliques*, to all of whom I stated: "For this condition I can do nothing."

The condition is real, the treatment is rational, and relief must follow. The condition is easy of detection, and the insufficient muscle can be quickly located. [In making the test, the line, the double prism, and the plane of the centers of direction of the two eyes should all be parallel. Observing this rule, no error of diagnosis is possible.] The double prism before the right eye, the middle line is seen by the left (the one under test); if it dips toward the opposite (right) side, the superior oblique is insufficient (see Figure 1); if toward the same side, the inferior oblique is insufficient (see

Figure 2). The same is true when the right eye is under test, as is shown in Figures 3 and 4. In the treatment, either concave or convex cylinders can be used. If the concave are used, and the insufficiency is in the superior obliques, the axes must be placed in the lower nasal quadrant; if in the inferior obliques, then the axes must be placed in the lower temporal quadrant. If for the exercise the convex cylinders are chosen, the axes must be placed in the lower temporal quadrant for insufficiency of the superior obliques, and in the lower nasal quadrant for insufficiency of the inferior obliques. In either case, the effect is increased as the axes are made to move from the vertical to the point of maximum effect, which is 45° from the vertical.

The exercise may be commenced with a .50 to a 1.00 D. cylinder, and increased each day a .50 D., up to 3.00 D. The cases will be very rare that will require a stronger exercise cylinder than the last named. The graduated exercise should be continued daily. Each eye being affected, the exercise cylinders should be placed before both.

Since the publication of the above paper, my experience has confirmed me in the belief of the correctness of its teachings. My first case continued to do well, and for some months has shown no evidence, either by the dipping of the middle line or by suffering, that there is any insufficiency of his obliques. He has continued to use his exercise cylinders from the beginning to the present; and that, too, in the face of my advice to discontinue them several months ago. His idea in continuing the exercise (for several months only once a week) is to keep the muscles strong. I have told him that too much exercise might reverse his trouble; but in his case nothing of the kind has occurred.

What is true of this first case is true of more than 300 additional cases that have been treated or are now under treatment. Experience has taught me that patients having well-marked insufficiency of the obliques should exercise twice a day for two months, once a day for another two months, three times a week for a month, and once a week for another month. If I cannot see the patients to apply the test, I take it for granted that they are cured at the end of six months. Usually the reports from such patients show a gradual diminution of symptoms, as to duration and severity, until finally there are no symptoms. Some get complete relief very soon after beginning the exercise; but such are always advised to continue through several months. If other ocular errors exist, they of course receive attention.

The cylinders I most frequently use are + 1.50. The great majority of cases are better treated with these than with weaker or stronger cylinders. Very slight cases should have weaker cylinders; while there are a few in whom the trouble is sufficiently great to require stronger cylinders, even a + 3.00. One case has been reported to me that required, during a part of the treatment, + 6.00 cylinders. As a rule I do not find it necessary to increase or decrease the strength of the cylinders in the course of the treatment.

Soon after beginning the exercise treatment on my first patient, it occurred to me that there should be contraction and relaxation alternating, in order to the more rapid and effective development of the muscles. At first I directed my patients to look at the light through the cylinders for a few seconds, and then close the eyes for the same length of time. I soon learned, however, from a study of the recti muscles, that a relaxation of the ocular muscles does not come quickly when the eyes are closed. To get rhythmic contraction and relaxation, I now direct my patients to look at the light five seconds through the cylinders; then look at the same light five seconds without the cylinders.

For the benefit of those who are interesting themselves in the study of "insufficiencies of the oblique muscles and how to correct them," I publish below cuts of frames which I have devised and use in my practice, prescribing the same almost daily. The frames are made of German silver, with circular rims for the lenses. These rims are deeply grooved to allow a free rotation of the lenses. The rims are marked at points 15 degrees apart, from 90° to 45°, in either the lower temporal or lower nasal quadrant, depending on the pair of muscles affected. The cylinders used are usually +1.50 D., and the axis of each is plainly marked as shown in the cuts. The frames are not marked nor are the cylinders cut except by the oculist's order.

Figure 1 represents a pair of exercise cylinders ordered for a patient's own use whose superior obliques are insufficient. The rims, as shown, are marked in the lower temporal quadrant, at four points 15 degrees apart, three of which are numbered 1, 2, and 3. The cylinders, whose

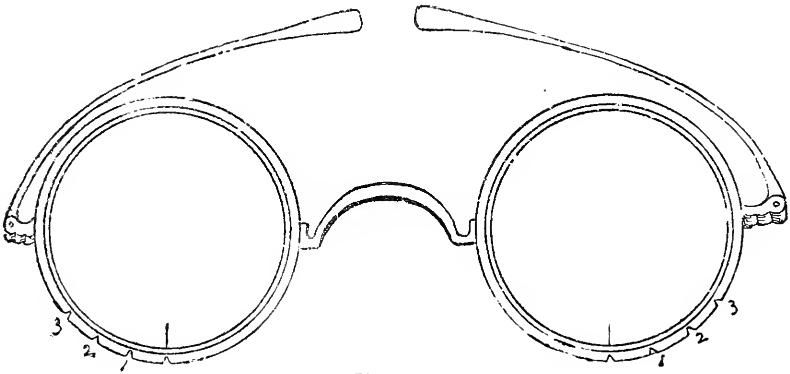

Figure 1.

axes are distinctly marked, can be readily revolved. The patient is directed to place the mark on each lens at the notch marked 1. Placing them now before her eyes, she is instructed to look at a broad lamp blaze, 10 to 20 feet distant, for 5 seconds, then without for 5 seconds, then again with for 5 seconds, and so on, for 5 minutes. Now the two lenses are to be revolved so that their marks coincide with No. 2 notch on rim. The flame is now looked at as above, for 3 minutes; when the last change in position of lenses is made by revolving their marks to notch No. 3, the point of maximum action. The patient now looks at the light, as above, for two minutes, which ends the exercise for that day—10 minutes in all.

Figure 2 shows the marking of rims when the patient has insufficiency of the inferior obliques, the exercise lenses to

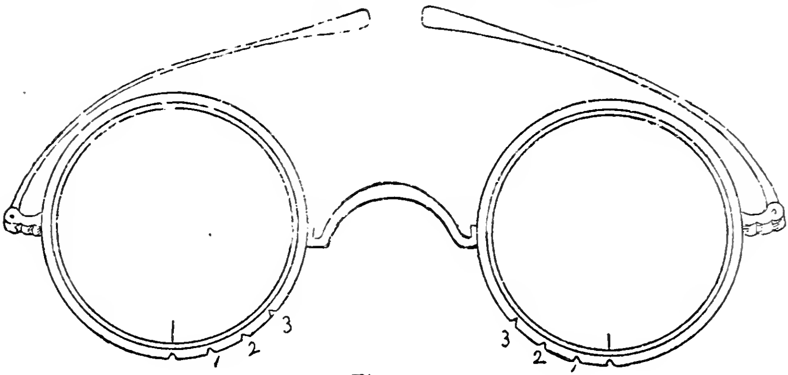

Figure 2.

be + cylinders. The revolution is made in the direction of the notching in both classes of cases. The points at which to stop and the time to look at the light are all the same. Insufficiency of the inferior obliques is far less common than that of the superior obliques.

The frames should be so made that the lenses will be properly centered. There is no patent on them, therefore any manufacturer may make them.

While in attendance on the Pan-American Medical Congress, it was suggested to me by Dr. Swan M. Burnett that, in at least some cases, the action of the superior and inferior recti, because of the nature of their scleral attachment, might throw an undue amount of strain on the oblique muscles. As is well known, the contraction of the inferior rectus not only directs the visual axis down, but also rotates the vertical meridian of the cornea out. The same action, with the same results, occurring in the fellow eye, there would be a divergence of these meridians above, unless counteracted by the superior obliques. The superior recti direct the visual axes up and rotate the vertical meridians so that they converge above. The latter result must be counteracted by the inferior obliques. In either case, the attachment of the superior and inferior recti might be such as to demand too much action on the part of the obliques, though intrinsically strong. It seems to me that this, as a reasonable factor, may enter into the causation of symmetrical insufficiency of the obliques. The fact that we call into action the inferior recti more frequently than we do the superior (we look down more than we look up), associated with the other fact that insufficiency of the superior obliques is far more common than insufficiency of the inferior obliques, leads me to look with still more favor on the thought suggested by Dr. Burnett. Still I believe that there are many cases of insufficiency of the obliques due to intrinsic weakness of these muscles. Often the two factors may be associated as a cause.

On hearing Dr. Burnett's suggestion I at once responded: "If you are correct, some cases of insufficiency of the obliques can be cured by dividing the offending fibers of the inferior (or superior) recti."

It seems to me that we may be able to determine this matter by varying our method of investigation. When, in a given case, the card and double prism being so held that the visual axes are horizontal, there is no dipping of the middle line, if, on changing the test so that the visual axes point a few degrees below the horizontal plane, the middle line should dip toward the opposite side, showing insufficiency of the superior obliques, it would appear that the cause exists in the inferior recti.

Whether the cause of insufficiency of the obliques be simple or complex, my experience leads me to believe that these cases can all be cured by the method of developing the obliques as set forth in this chapter. Even when it can be proven that the inferior recti enter into the causation of insufficiency of the superior obliques, the effort should first be made to cure by the exercise of the latter; should this fail, then a well-directed operation on the offending fibers of the inferior recti might be done.

In commenting on this chapter (Chapter II. in the first and second editions of this book), critics have differed widely. Some have claimed that they have not been able to discover the condition in a single case; while others, among whom is Dr. Eaton, claim that the phenomena might be brought out in almost all cases. So common did this latter class find the condition that they pronounced it to be normal. Between these two extremes is to be found the truth. Not more than twenty-five per cent. of cases, the double prism being used, will show insufficiency of the superior obliques; while less than one per cent. will show insufficiency of the inferior obliques. Within the past few months a most remarkable case of insufficiency of the inferior obliques has been observed. So marked was the dipping of the middle line toward the corresponding side that it took a plus 6.00 cylinder, revolved through an arc of 45° from the vertical, to parallel the lines. As great as was this error, the patient had not suffered at any time much inconvenience in reading or writing, which of course was done below the horizontal plane. Anything like this quantity of insufficiency of the superior obliques would have rendered her wholly incapable of any comfortable seeing, even in the horizontal plane.

Soon after beginning the treatment of the obliques, and before Dr. Wilson had written his criticism of my method of treatment, I had observed that some patients did not improve, while others had marked improvement. Some patients even got worse under the treatment. On investigating these cases it was soon brought out that those who were not improving were exercising their eyes while looking at the blaze of a candle; while those that improved most rapidly exercised while looking at a broad lamp blaze. From that time on I directed that all patients should use the broad lamp blaze when exercising, and never the pointed blaze of a candle. It is certainly true that artificial oblique astigmatism will call into action either the superior or inferior obliques, depending on the character of the blaze looked at. The plus cylinders revolved in the lower temporal quadrant, intended for exercising the superior obliques, will unquestionably call into action the inferior obliques if there is more of the vertical area of the retina, than of the horizontal, impressed by the image of the light. This is exactly what would occur if the candle were used. For this reason the word "candle," wherever it appeared in this chapter in former editions, has been stricken out. Better still than a broad lamp blaze is a horizontal slit in an opaque metal chimney. The chimney, bright within and dark without, should be rectangular, and should be made large enough to fit over an Argand burner, or even a large lamp chimney. The slit should be long, and perfectly horizontal. It might vary in width from an eighth to a quarter of an inch. Looking at this slit through the plus cylinders, revolved in the lower temporal quadrant, would call into action only the superior obliques; while the same cylinders, revolved in the lower nasal quadrant, the patient looking at the same horizontal streak of light, would call into action the inferior obliques.

Careful observation will serve to convince any investigator of the fact that there is such a thing as insufficiency of the oblique muscles. A careful study of the cases in which this condition is found will show that at least a part of the nervous phenomena which they exhibit is dependent on the existence of this condition. Two evidences may be observed as to the good effect of the treatment of insufficiency of the obliques, as set forth in this chapter: the one, a parallel condition of the three lines when under the double prism test, a revolution of the proof cylinders in either the one direction or the other from the vertical, through an arc of 5°, causing the middle line to dip either to the right or to the left. The other evidence is that the patient gets relief from the nervous symptoms which had depended on the existence of this muscle error. However many ocular errors may be found in any one case, the operator, guided by the proper indications, should feel it his duty to treat them all.

If what is taught in the first four chapters of this book is false, then the teaching of this chapter cannot be correct, so far as the treatment of the obliques is concerned; nevertheless it would remain a fact that there is such a condition as insufficiency of the obliques. But if the teaching of these four chapters is correct, then not only is the teaching of this chapter correct as to the existence of insufficiency of the obliques, but it is also correct as to the treatment of this condition. If natural astigmatism calls into activity either the superior or inferior obliques, the meridians of greatest curvature diverging or converging, then the production of artificial astigmatism must be able to do the same thing. The making and unmaking of artificial oblique astigmatism will call into rhythmic contraction and relaxation either the superior or inferior obliques, as may be desired by the operator.

A New Method of Testing the Obliques.

One of the easiest, quickest and surest tests for insufficiency of the oblique muscles is by means of the Wilson phorometer. The rotary prisms should be placed for testing sursum- and deorsum-duction. The rotating of the prisms should be continued beyond the strength of the muscle to prevent diplopia. If the sursum-duction is 3°, the rotation should be carried to 4° or even 5°. The false line will appear above the true one, but will be parallel with it if the inferior oblique is sufficiently strong to counteract the torsion effect of the acting superior rectus. By reversing the action of the prisms, the two lines will be simultaneously fused throughout their entire length. Should the inferior oblique be weak, the false line being seen by the left eye, the two lines will converge at the left; and the left ends of the two lines will fuse first, when the rotation of the prisms is reversed.

If the displacement is such as to call into action the inferior rectus, when carried far enough to cause diplopia, the false line (the lower) will be parallel with the other, if the superior oblique is strong enough to counteract the torsion effect of the acting inferior rectus; but if the oblique is not strong enough to accomplish this result, the two lines will converge at the left. Reversing the action of the prisms, the left ends of these lines will fuse first. In my own case the lines are parallel when the false one is above, but converge at the left distinctly when the false line is made to appear below. Reversing the action of the prisms, when the false line is above, the two fuse throughout at the same moment; but when the first line is below, fusion of the left ends takes place first. Just the reverse is true in Dr. G. H. Price's case.

The test can be made both in the far and the near. If the distant test should show no leaning of the false line, but the near test should reveal it, at once suspicion of error of attachment of the interni would occur. Such error of attachment of the interni would not only converge the visual axes, but would also effect torsion in one direction or the other, which would manifest itself or not, depending on the quantity of the corrective power of the obliques.

Dr. Maddox, of Edinburgh, was the first to call attention to the delicacy of the test of the obliques by means of revolving a single prism, which had caused vertical diplopia, in such a way as to fuse the two lines. Insufficiency of the obliques will allow fusion at one end first. When the base of the prism was down, its revolution tested the inferior oblique; when the base was up, its revolution tested the superior oblique, a statement not made by Dr. Maddox.

The delicacy of the test of the obliques by the Wilson phorometer will no doubt show a larger per cent. of cases of insufficiency of both the superior and inferior obliques than could be found by the double prism test.

All the cases thus found need not be treated. If in both the sursum and deorsum tests, the superior obliques should show weakness by the false line, when above, leaning to the opposite side, but not to so great an extent as when below, certainly these muscles should be strengthened by exercise. On the other hand, when the false line is below and inclines toward the corresponding side, though not so much as when above, the indication for treating the inferior obliques is strong.

I have not seen such a case, but I believe it possible for the false line to incline in one direction when above, and in the opposite direction when below the true line, thus clearly showing insufficiency of both the superior and inferior obliques. This might be so great as to require the exercise of each pair (the two superior being counted a pair and likewise the two inferior) at least once in the twenty-four hours. Such a condition of the obliques would be like asthenic orthophoria.

CHAPTER VI.

RELATIONSHIP BETWEEN THE CENTERS OF ACCOMMODATION AND CONVERGENCE.

THAT there is a relationship between accommodation and convergence has long been taught; but the full extent of this relationship and its consequences have not, to the present, been fully set forth in any published work. There is more in it than the simple fact that, for every degree of convergence, there is a corresponding activity of the accommodation. In a pair of emmetropic and orthophoric eyes this is probably all, and it is enough; but in the many eyes not thus happily conditioned there is much more than this dependent on the intimate relationship between these two centers.

There is no study more interesting than that of the nuclei (the centers) beneath the aqueduct of Sylvius and in the floor of the fourth ventricle; and of these centers not the least in interest is the study of the oculo-motor center, the one first in position and first in importance. It is the largest of these centers, and itself is the home of several centers. As a whole we may speak of it as controlling the sphincter of the iris, the muscle of accommodation, the internal rectus, the superior and inferior recti, and the inferior oblique; but for each of these muscles there is, in this nucleus, an individual center, the first three of which—viz., that for the sphincter of the iris, that of accommodation, and that of convergence—are so intimately related that, when one is excited into activity, the other two either act or stand ready for action. All of the centers of the oculo-motor nucleus have one common master, which is the *guiding sensation* residing in the retina, its home being the *macula lutea* and its immediate neighborhood. The two ocular centers (the fourth and the sixth), situated farther back, are also under the control of this same *guiding sensation;* but it is not intended, in this paper, to study these and their relationship to each other and to the centers of the oculo-motor nucleus.

The oculo-motor center not only has connection, by means of nerve fibers, with the muscles already named, but it also receives fibers from the retina through the optic nerves and tract, through which the *guiding sensation* sends its commands or requests. This center also has an intimate connection with its fellow-center of the opposite side, which enables them to act in harmony, although the one can never act for the other.

From this brief study of the centers giving motility to the eyes, we may pass on to a study of the two most intimately connected centers, the one of accommodation and the other of convergence. As already intimated, the whole truth is not embodied in the statement that, for every degree of convergence, there is a corresponding contraction of the ciliary muscle (in persons under 45 years of age and emmetropic). The following statement is full of truth, and is for the first time made: *Whenever one of these centers is called into activity there is a* TENDENCY *on the part of the other to become active in a corresponding degree.* If the associated center does not put forth action, it is because the *guiding sensation* commands it not to do so; or the center no longer has its proper organ under its power. In one of these ways is explained the dissociation of these centers by prisms affecting convergence, and by convex and concave lenses affecting accommodation; in the other way is explained the failure of the accommodative center to exhibit activity corresponding to convergence in the eyes of the old, and in young eyes that are under the influence of a mydriatic, and in aphakial eyes.

When prisms are placed before the eyes, the bases in, less convergence is needed, but the same accommodation must be exercised. It is only because of the imperative command of the *guiding sensation* that the accommodation does more than its accustomed work for the degree of convergence exercised; and, too, under this new condition, the unusual activity of the accommodation excites a *tendency* to greater activity on the part of the internal recti, which is kept in abeyance by the guiding sensation.

When properly centered convex lenses are placed before young, emmetropic eyes, while the patient looks at a book, the two centers are dissociated in *action* but not in *tendency*. Under this condition the guiding sensation compels the ciliary muscle to relax in part or in whole, depending on the strength of the lenses used, which excites in the converging centers a *tendency* to relax, which is prevented by an unusual demand on this center compelling it to effect the needed amount of convergence; and, on the other hand, this excessive (proportionately) demand on the centers of convergence excites a proportionate *tendency* to action on the part of the centers of accommodation, which is alone restrained by the guiding sensation.

Again when properly centered concave glasses are placed before the eyes, there is dissociation of *action* but not of *tendency*. On looking at the page, more than the usual amount of accommodation is necessary in order to have sharp images on the retinæ. This extra demand on the accommodative centers is not attended by a corresponding increase of convergence, because the guiding sensation suppresses the *tendency*.

Dissociation of accommodation and convergence, in normal eyes, is never comfortable, and the discomfort is due as much to the *restraining* influence of the guiding sensation over the one center as to its *exciting* influence over the other.

When accommodation and convergence are dissociated by age, or by the continued influence of a mydriatic on the ciliary muscle, or by the removal of the crystalline, the center of accommodation not only becomes unable to influence the center of convergence, but also becomes incapable of being influenced by it. Such dissociation, *per se*, is never attended by the discomfort that is brought about in dissociation by means of prisms and convex and concave lenses.

There are conditions modifying the salutary association of these two centers, from which result phenomena that may be clearly understood. There may be but one unfavorable condition, or there may be two or more associated. Of the disturbing conditions we may speak first of

Hypermetropia,

simple or associated with astigmatism. For the present we will consider this condition as unassociated with any form of heterophoria, at least as far as the external and internal recti are concerned. The hypermetropia, for convenience of study, may amount to 3 D. The existence of this error creates a demand on the accommodative centers when vision is fixed on distant objects. The activity of these centers, when the visual lines are parallel, excites a *tendency* to activity on the part of the converging centers, which is suppressed by the influence of the guiding sensation so long as the two eyes are on their guard; but let any one of the several tests for heterophoria be applied, the guiding sensation loses its "grip," and the *tendency* to act is converted into *unrestrained action*, and we have esophoria shown which has no foundation in the structure or attachment of the internal recti. When these eyes are used in near work—at a distance of fourteen inches—there is twice the demand on the accommodative centers that would be made were there emmetropia. The excessive excitation of the accommodative centers is necessarily attended by a corresponding disposition for greater activity on the part of the converging centers than is necessary for bringing the visual axes together at the point looked at; but the guiding sensation suppresses enough of this *tendency* to prevent the axes coming together at a shorter distance. The test for heterophoria is applied and, the guiding sensation having lost its influence over the converging centers, esophoria in the near is shown. The practical deduction to be made from this observation is that *a full correction of the hypermetropia will relieve not only the focal error, but the esophoria as well.* The wearing of these correcting lenses continuously will relieve, from the beginning, all asthenopic symptoms of whatever nature. And, too, this form of esophoria (pseudo-esophoria) disappears when accommodation is suspended by age.

Again, hypermetropia may be associated with an

Esophoria

which depends on an overdevelopment of the internal recti, or on their attachment being too far forward, or on both of these causes combined. If the intrinsic esophoria is low in degree, although it will be increased by the hypermetropia, the only resulting phenomena will be asthenopic symptoms of one kind or another, the disposition on the part of the center of convergence to overact being restrained by the guiding sensation. On the other hand the inherent esophoria will have no undue influence over the accommodative centers; hence there is never found in such eyes even a tendency to true spasm of accommodation.

The practical deduction made from our study of hypermetropia complicated with inherent esophoria, is: *Give a full correction of the hypermetropia and, in that way, relieve not only the focal error, but also relieve all of that part of the esophoria not inherent in the muscles.* Should the remaining esophoria give trouble, it must be corrected by either rhythmic exercise of the externi or by partial tenotomies of the interni, or by both procedures.

Esophoria depending on hypermetropia solely is wholly relieved by advancing years, as well as by glasses that fully correct the focal error. It is also relieved, after the first few hours, by the use of a mydriatic, and this relief continues with the continued use of the drug. A very peculiar feature of the use of a mydriatic is that, at first—probably from one to several hours—a mydriatic, in hypermetropic eyes, will increase the esophoria, will lessen an exophoria or convert it into orthophoria or even into an esophoria. Until now this has been unexplained; and the following explanation is not only new, but it must be true: The mydriatic acts on either the endings of the accommodative nerve fibers, or on the fibers of the muscle of accommodation, certainly not on the accommodative centers, which, therefore, must remain in a state susceptible of excitation by the demands from the guiding sensation. As the muscles of accommodation pass into their forced rest, the retinal images become less sharp in outline, the blurring increasing up to the point of full suspension of accommodation. The guiding sensation calls on the accommodative centers for sharper images, and the impulse is sent out, but finds the muscles unresponsive; the call is repeated more eagerly, and a stronger impulse is sent to the sleeping muscles, and still no change is effected in the images; and thus the calls and the responses are kept up for a longer or a shorter time. For every degree of activity excited in the accommodative centers there is a corresponding *tendency* to activity generated in the converging centers, which is kept in abeyance by the same guiding sensation that is calling for action on the part of the accommodative centers. So long as the calls are made on, and responses are made by, the accommodative centers, the centers of convergence stand ready to call into unusual action the interni, which they do the moment the guiding sensation is robbed of its restraining power by the test for heterophoria, when esophoria is shown. But finally the guiding sensation ceases its calls, or, from exhaustion, the accommodative centers cease to respond, and now the normal muscular condition is again shown, and will remain manifest although the mydriatic may be continued. From this observation on the mydriatic as a disturber of the salutary relationship of the centers of accommodation and convergence, we deduce the following conclusion: *All tests for lateral heterophoria are wholly unreliable within the first few hours after eyes have been brought under the influence of a mydriatic.*

Again, hypermetropia may be associated with an intrinsic or true esophoria of so high a degree that, while the guiding sensation calls into activity the accommodative centers, that sharp images may be formed, there is excited in the converging centers a *tendency* to activity which cannot be restrained by the guiding sensation, and there results

An Internal Strabismus.

In many cases of strabismus, the intrinsic esophoria could be restrained by the guiding sensation, if the eyes were only emmetropic or even myopic; but there being hypermetropia to excite pseudo-esophoria, this, combined with the true esophoria, throws off the *restraining* influence of the guiding sensation, and esotropia results. This condition, as is well known, occurs mainly in early childhood, when accommodation is most powerful, and when there is a natural disposition on the part of the child to hold an object too near the eyes. Many children with crossed eyes would never have been thus disfigured if they had not been allowed to look at things attractive to them, at too short a distance from the eyes. With the above thought in mind it is plain to us how many crossed eyes may be straightened, in early childhood, by suspending the accommodation and correcting the focal errors, by means of which the cause of the pseudo-esophoria is removed, leaving the true esophoria to be called back into a state of suspension by the guiding sensation. The practical conclusion reached is this: *Give a full correction of hypermetropia in all cases of internal squint.* Such a correction cannot be determined without first bringing into a state of rest the hyper-developed ciliary muscles. Without the further use of a mydriatic, many cases of esotropia can be corrected by the continuous wearing of the convex lenses; but there are many other cases in which the mydriatic must be used for a long while, in order to prevent any excitation of the accommodative centers in near seeing, and thereby completely preventing the slightest pseudo-esophoria. It takes a mydriatic, in some cases, to subdue ciliary muscles that have become overdeveloped, which, in spite of the correcting lenses, would exert too much power in response to an impulse from the accommodative centers, which impulse, because of long habit, itself might be too great. This over-action (the lenses being on) has been falsely termed spasm of accommodation, a condition which can have no existence except as a result, or complication, of exophoria. It is only a continuance of a part of that action which was necessary before the correcting glasses were given; and as the action, when necessary, caused pseudo-esophoria, the continued action, when not necessary, will likewise cause the same, hence the necessity for the mydriatic. Should the ciliary muscles become quiet without a mydriatic, when objects at a distance are made to throw their images on the retinæ by means of lenses, the guiding sensation would call their centers into activity, when an object looked at is near by. This needed stimulation of the accommodative centers will excite an excessive *tendency* to act on the part of the converging centers, and there results squint in the near, the same disappearing when distant objects are again viewed. We conclude then that, while some crossed eyes may be straightened by glasses only, it is better to aid the glasses, in all cases, by the long-continued use of the mydriatic. Nor should the fact that a mydriatic, at first, increases the strabismus, deter any one from using it; for, as already explained in this paper, when speaking of the effects of a mydriatic in cases of esophoria, exophoria, and orthophoria, this stimulating effect passes away in a few hours. In a case recently under our observation, the increased effect lasted only an hour, when the strabismus began to lessen and, in a short time, disappeared, solely as a result of the mydriatic. Stevens was the first to notice that a mydriatic not only was capable of increasing an esotropia, but actually produced it in one of his cases, which he published but did not explain. Since then we have observed its power to increase internal squint in all our cases, but have not been able to understand why until now.

In the correction of esotropia by mydriatics and lenses, the pseudo-esophoria has been destroyed, and the esotropia has been converted into true esophoria, which must be relieved at some time by partial tenotomies, shortening of the external recti, or by rhythmic exercise. In many cases two or all of these procedures will have to be combined. Without them the intrinsic esophoria will remain always and be a perpetual source of nervous phenomena.

Intrinsic Exophoria

may be classed among the causes of disturbed relationship between the centers of convergence and accommodation. To prevent crossed diplopia, the inherent power of the strong external recti leads the guiding sensation to call the centers of convergence into excessive activity. In this way the weak internal recti counteract the more powerful externi. This augmented action of the centers of convergence excites a corresponding *tendency* to act on the part of the centers of accommodation, which, in most cases, is restrained by the guiding sensation; but in some cases the *tendency to action* of the accommodative centers, when the interni are weak, becomes uncontrollable by the guiding sensation, and real spasm of accommodation (pseudo-myopia) is developed. The spasm may be thus excited in emmetropic, hypermetropic, or myopic eyes, and is to the muscle of accommodation what esotropia is to the interni—in each the guiding sensation has lost its power to control a tendency excited by a disturbance of the normal relationship between the centers of accommodation and convergence.

The *tendency* to act excited in the accommodative centers by the overacting centers of convergence, whether suppressed by the guiding sensation or not, strengthens the converging centers in their mastery over the weak interni, and this, too, in all eyes, whether emmetropic, hypermetropic, or myopic. But whatever may be thought of the *tendency* to activity excited in the centers of accommodation by overtaxed converging centers, making the latter stronger, it cannot be doubted that actual ciliary strain, such as is necessary in hypermetropic eyes, does give to the converging centers easier and more complete control over the interni. The reason for this has already been made clear. Therefore this reasonable deduction: *Hypermetropia, when associated with exophoria, should not be corrected if low in degree, and should be only partially corrected if great in quantity. The greater the exophoria the less of the hypermetropia should be corrected.* The ciliary strain necessary for the correction of 1 D. to 3 D. hypermetropia is more kindly borne by the nervous system, in many cases of exophoria, than would be the pseudo-exophoria which the correcting lenses would engender. Thus there is a reason for making no correction at all, or only a partial correction, of hypermetropia in certain cases (the exophoric); while, on the other hand, there is every reason for making the fullest correction in other cases (the esophoric).

Who has not seen one or many hypermetropes wearing comfortably concave lenses, who could not bear the use of convex lenses? Such cases have always been exophoric. For the same reason an emmetrope who is exophoric could wear, with increased comfort, concave glasses. In myopia of 3 D. there is no ciliary strain required, hence the guiding sensation never makes a demand on the center of accommodation. This is well in cases of esophoria, so far as comfort is concerned; but in orthophoria and exophoria a correction of the myopia would greatly increase the comfort of seeing at all distances.

As convex glasses and mydriatics will correct an esotropia, so concave glasses and myotics should correct an exotropia; but as to the last statement we have had no experience. In neither case is the intrinsic muscle error corrected (cured)—it is only held in abeyance the more easily.

The first effect of a mydriatic when instilled into eyes that are hypermetropic and esophoric will be attended by suffering more or less severe, while the reverse is true in cases of hypermetropia associated with exophoria. The reason is clear.

The conclusions of this paper may be placed together here:

1. Give a full correction of hypermetropia when associated with esophoria.

2. Give no correction, or only a partial correction, of hypermetropia when associated with exophoria.

3. Give a full correction of myopia when associated with exophoria, and when there is orthophoria.

4. For near work give only a partial correction, or none at all, of myopia when associated with esophoria. A full correction may be given for distant seeing.

5. A full correction of hypermetropia cures a pseudo-esophoria in esophoric cases, and creates a pseudo-exophoria in exophoric cases.

6. A full correction of myopia cures a pseudo-exophoria in exophoric eyes, and creates a pseudo-esophoria in esophoric eyes, when engaged in near work.

7. In hypermetropia associated with internal strabismus, fully correcting lenses, aided by mydriatics, remove all pseudo-esophoria and thus make it possible for the guiding sensation to resume control of the converging centers, in such a way as to restrain the true esophoria, and thus cure the strabismus.

8. In myopia associated with exotropia, fully correcting lenses, with myotics, will remove pseudo-exophoria and thus

make it possible for the guiding sensation to restrain the true exophoria, and thereby cure an external squint.

9. Any test for lateral heterophoria, within the first few hours after beginning a mydriatic, is wholly unreliable, even with lenses on.

The above conclusions are based on the idea that nothing is to be done for the direct relief of the muscle errors. A better practice would be to cure the heterophoric conditions by rhythmic exercise, when possible, otherwise by operations (partial tenotomies and shortenings) and rhythmic exercise, and then give an approximately full correction of whatever focal error there may be.

When this chapter was written we had no knowledge of the existence of a paper by Dr. A. B. Norton, of New York, on the question "Can Headaches and Asthenopia, Resulting from Hyperopia, Be Relieved without Glasses?" Soon after we had written, a letter came from Dr. Norton calling our attention to the fact that thoughts very much akin to those which we had embodied had been published by him in the October, 1890, issue of the *Journal of Ophthalmology, Otology and Laryngology*. The first quotation we would make from Dr. Norton's paper is as follows:

"I do not wish to be understood as making the claim that no case of hyperopia needs glasses, or that all cases of headaches in hyperopic patients can be cured without glasses; but simply desire to point out a new factor, which, in my opinion, renders the need of glasses unnecessary in many cases that have heretofore been considered as demanding their use; and further that, in those cases in which the necessity of glasses still seems to be imperative, improper glasses may be prescribed from a lack of careful examination as to the condition of the recti muscles."

The chief thought which the Doctor intended to express in his paper, and to which he applied the term "new factor," is the strengthening of the ciliary muscles as a result of exercise of the internal recti. Incidentally he brings out the fact that, in prescribing lenses for hyperopia, the strength should be determined, not wholly by the quantity of the defect, but in part by the relationship shown to exist between the opposing lateral muscles. The thought that by increasing the power of convergence the accommodative power would also be increased, he believes to be "supported by the fact that when we put on a convex glass in hyperopia, with exophoria, or a weakened power of convergence, we cause a greater exophoria with a diminished incentive to convergence, and thereby diminish the power to converge, with the result that the more delicate ciliary muscle, with but a small fraction of its full power still left unused, is called upon to perform a certain portion of the work of its much stronger associate muscle, the internal rectus; and thus, by increasing the demand upon an already weakened muscle, I believe that serious harm may be done."

In closing his paper he drew the following deductions:

"1. Always examine the muscular deviation with and without the correcting lenses, as convex glasses will increase exophoria and decrease esophoria.

"2. If exophoria exists with hyperopia, always prescribe the weakest glass possible or none at all.

"3. If esophoria is found with hyperopia, prescribe the glass that corrects the esophoria, or as nearly so as possible."

Those wishing to read all of Dr. Norton's paper from which we have quoted can find the same in the copy of the journal already referred to. The paper is richly worth the reading.

CHAPTER VII.

RHYTHMIC EXERCISE THE PROPER METHOD OF DEVELOPING THE OCULAR MUSCLES.*

THE development of the ocular muscles, by means of gymnastic exercise, has received but little attention from modern authors. Noyes devotes about one page to the subject; DeSchweinitz, less than one page; Schmidt-Rimpler, three lines, as follows, "No improvement is to be expected, as a general thing, from exercise of the interni; overexertion, that is apt to occur, may result, on the contrary, in a serious impairment of their power;" Fuchs, not a line; Berry, not a line; Meyer, ten lines; Landolt, not a line; Wells, one paragraph of ten lines; Schweigger, not a line; Nettleship, not a line; Juler, not one word; Carter, not a line.

Those of the twelve authors above named who teach anything on the subject teach the same thing. This teaching is illustrated by the following quotation from DeSchweinitz: "Thus, to exercise the interni [in exophoria] a prism of 10 degrees is placed base out before one eye, and as soon as the diplopia produced is overcome, 5 degrees more are

* Published in the *Ophthalmic Record*, May, 1893.

added, and so on until the limit of adductive power is reached. . . . These exercises should be repeated every day for ten or fifteen minutes at a time, until the patient has acquired the power to overcome readily a prism of 50°." He recommends the same character of exercise for developing the externi, beginning with a 3° prism and increasing to 8°.

Noyes, following Dyer who wrote on this subject in 1865, says: "He [the patient] takes a candle flame or door knob at twenty feet for his object, and performs the efforts of adduction and abduction by means of these prisms. He begins, say, with adduction, and at first holds the prism of 5°, with base out, before one eye; then substitutes the 10°; then before the other eye places 5°, making a total of 15°; then, if practicable, substitutes the other prism of 10° for the 5°; and so climbs up the ladder of adduction prisms by such steps as he can make. If the interval of 5° becomes too great, he may take that of 2½°." He speaks of the exercise of the externi after the same plan, using weaker prisms with their bases in. He directs that the exercise be continued ten minutes at each sitting, and that it be repeated not oftener than twice a day, until, in the case of the interni, a prism of 42½° can be readily overcome, and, in the case of the externi, a prism of 10°. The prism of maximum strength having been reached, its use should be continued, says this author, once daily for a time. Noyes closes by saying: "A decided gain in comfort and use of the eyes may be obtained by this proceeding; and if this result is not adequate, the true state of the muscular relations is brought to view."

It is not necessary to make further quotations in order to bring clearly into view the character of the exercise. It is the object of this paper to show that the plan is unsound in principle, and must necessarily be unsuccessful in practice. Continuous muscular contraction, augmented at short intervals for 10 minutes, or for even 5 minutes, may show what a muscle is capable of doing in an emergency; but it is not calculated to build up or develop the inherent power of the muscle.

In a modified form Dr. Charles E. Michel, of St. Louis, has persistently practiced the development of weak internal recti muscles by means of prisms, since 1877. The prisms used by him have not been stronger than 4°, nor weaker than 1°. Beginning with the weaker prism, he directs the patient to exercise frequently (ten to fifteen times) during the day, each period of exercise to last only four or five minutes for the first few days; later they are to be worn only four or five times daily, increasing the time of exercise by two to five minutes daily, until they can be worn comfortably one hour. When the patient, looking in the distance, becomes able to wear the 4° prism one hour without discomfiture, he is directed to commence reading. At first he must read only from three to five minutes at a time; but later he increases this time by two to five minutes daily, until he can read comfortably one hour, four times a day. Whenever this can be done, the patient is directed to continue for several months the reading exercise practice for half to one hour, two or three times a day. To suit individual cases, modifications as to strength of prism and length of time and frequency of exercise must be made.

Under Dr. Michel's treatment, fully 60 per cent. of his patients have full muscular power developed, and in this way are enabled to use their eyes with comfort; 25 per cent. have greater or less gain in comfort; while 15 per cent. derive no benefit from the treatment. As a preliminary step to the muscle treatment, the Doctor always corrects any existing refractive errors, and has the patient wear these lenses behind the exercise prisms.

Dr. Michel's method of developing ocular muscles is given for the reason that it differs essentially from that set forth in the books, and for the additional reason that a high percentage of cures results from his method. The Doctor's success has been due to the fact that his weak prisms used made but little demand on the weak muscles, thus making it possible for the continuous contraction to be borne and the muscle strengthened.

In contrast with Dr. Michel's practice, the method of Dr. George T. Stevens, of New York, is here given in his own words: "Adduction may be greatly improved by gymnastic exercises of the interni, by means of prisms. In these exercises, the eyes are required to unite images in overcoming gradually increasing obstacles. A prism of a few degrees, perhaps 10°, is placed, base out, before one of the eyes, while gazing at a lighted candle at twenty feet distance, when an effort is at once made to prevent diplopia. As soon as the images are blended, another prism, of perhaps less degree, is placed in the same manner. The images being united, a stronger prism takes the place of one of those already in place, or one is added to those already in position. Thus, little by little, the eyes are required to overcome prisms until the images can no longer be united. Then all the glasses are removed, and the process is repeated; with each repetition something may be gained. The exercise should not be continued, at a single sitting, more than five or six minutes; and only a single sitting daily is desirable. By this means the adducting power can, in most cases, be raised after a few exercises to the desired point.

"The effect of such exercise upon the eyes is very often extremely salutary. With greater freedom of muscular action comes a sense of relief from nervous strain, which is often of a most gratifying character. Such an exercise is in no way related to the practice sometimes adopted, and which should be condemned, of requiring the patient to gaze for a long time at a near object."

The virtue of Dr. Michel's method lies in the fact that, though he taxes the muscles for a long while, gradually reaching the maximum of time, he taxes them but slightly, using only weak prisms; while the virtue of Dr. Stevens's method lies in the fact that, while he taxes the muscles severely, using the strongest prisms possible, reaching the maximum strength by degrees, he does not continue the exercise very long and does not repeat the sitting again the same day. And, too, he almost strikes the right principle in his method of intermitting the exercise.

In contrast with both of these methods, and with the method laid down in the books, the method of

Rhythmic Exercise

will now be given, the author feeling confident that it is founded on sound principles and that it can, therefore, be carried out successfully in practice.

Contraction and relaxation, alternating in short and rhythmic order, and continued short of fatigue, is the kind of exercise that *develops* a muscle in any part of the body. It is the alternate contraction and relaxation that develops the muscles of the arm of the blacksmith. If the forearm should be flexed on the arm and held in that position ten minutes, no one would suppose that the muscles concerned could be developed thereby. There would be greater reason for believing that such action would enfeeble the muscles. This is precisely the kind of contraction effected by prisms in the old method of exercising the recti muscles. There can be no wonder that better results have not followed, and that the practice has been abandoned by almost all oculists.

This paper would be of little worth if it condemned the old practice as bad without setting forth a new line of practice, based on sound principles, and one that must be successful, in suitable cases.

While rhythmic contraction and relaxation, regulated as to intensity and time, will develop any one of the recti muscles, as is developed the biceps of the blacksmith, the writer would not be understood as believing that one of these muscles can be developed out of a *low* state of weakness into a *high* state of strength. There are case of exophoria that will remain exophoric still in spite of long-continued rhythmic and graduated exercise; and these cases, to be cured at all, must be cured either by partial tenotomies alone, or by these supplemented with rhythmic exercise. The same may be said of esophoria and hyperphoria. Only low degrees (not more than 6°) of lateral heterophoria can, by rhythmic exercise alone, be converted into orthophoria; the highest degrees can be corrected by partial tenotomies, shortenings, and exercise combined. While, in suitable cases, the aim of partial tenotomies and shortenings should be to approach orthophoria, yet the greatest care should be exercised not to go beyond the "balance" line. The safest thing is to leave, for correction by exercise, some of the original condition.

In attempts to develop the ocular muscles after the rhythmic contraction and relaxation method, it must not be forgotten that the extrinsic muscles of the eye are under the control of the guiding sensation in the retina, through the will.

Any one of the recti and either of the obliques weaker than its opposing muscle, the difference in corresponding strength not being too great, may be developed by rhythmic exercise into a state that will enable it to work harmoniously with its fellow.

Exophoria.

Exophoria may be taken first for study. The quantity should not be more that 6°. The internal recti are the muscles wanting in strength. There are two plans of exercise, rhythmic in their nature, by either one of which, or by both combined, these muscles can be strengthened:

1. The wax taper method;
2. The method by prisms, bases out.

The exercise with the taper (small wax candle) must be conducted as follows: The patient is directed to light the taper and hold it at arm's length from, and on a plane with, the eyes, immediately in front of the face. Fixing his vision on the flame, he continues to look at it while he brings it slowly to within five inches of his eyes, holding it there about two seconds. He then closes his eyes for a moment, and on opening them he fixes his vision on some object, preferably the flame of a candle or lamp, twenty feet or more distant. The same procedure is gone through with a second time, and so on for six to ten times at the one sitting. The sittings may be repeated two or more times daily for weeks or months. The best time for this exercise is early in the morning, while the muscles are fresh from sleep. In many cases the morning sitting will be sufficient for the day. This is especially so if the exophoria is low in degree. Reading or other near work should not be done within the hour after exercise.

In this taper exercise no one can doubt that the guiding sensation compels the internal recti to contract as the light advances, the maximum of contraction being reached when the taper is five inches from the eyes. On closing the eyes partial relaxation of the interni occurs (keeping the eyes closed long enough, the relaxation would become complete). The moment the eyes are opened and the vision is fixed on a distant object, in quick response to the guiding sensation, the relaxation becomes complete. Thus is brought about contraction and relaxation, which should be discontinued short of fatigue. That this rhythmic exercise, properly regulated as to frequency and to force, will develop the internal recti is susceptible of demonstration on the part of any one who wishes to know the truth.

The second method for developing the interni is by means of prisms, bases out. The prisms to be used may be from 1° to 8°, and one should be placed before each eye. The treatment should be commenced with the weaker prisms; and as development of the muscles advances, the stronger should be brought into use. The object looked at should be a candle, lamp, or gas jet, fifteen to twenty feet distant. The prisms before the eyes, the image in each of the two eyes is displaced out, and the guiding sensation calls quickly into action the interni. After five seconds the interni must be allowed to relax for the same length of time (five seconds), which is readily effected by lifting the prisms up and allowing the light to enter the eyes uninfluenced. The guiding sensation at once causes the relaxation to take place, so that the yellow spots may receive the images. At the end of this five seconds, the prisms are again dropped before the eyes, and the interni again contract. Then a second time the relaxation is effected by lifting the prisms; and so on throughout every sitting, which should last from two to ten minutes, but always discontinued short of fatigue. The sittings should be repeated two to five times a day. While it will take weeks if not months to establish orthophoria, nevertheless this end can be attained, in suitable cases, by this method. It may be better in most cases to resort to the two methods of development, the taper and the prisms, each day, but not at the same sitting.

In resorting to the prism exercise, it would be more convenient to close the eyes, for the purpose of getting relaxation, than to lift the prisms. When the eyes are closed the relaxation is slow to take place, and is rarely complete at the end of sixty seconds; whereas, when the prisms are raised, the guiding sensation effects at once complete relaxation, which continues until the prisms are again placed before the eyes. The rhythmic nature of the exercise is more perfect in the latter than in the former, and results are better necessarily.

Esophoria.

In this condition the muscles to be built up are the external recti. There is but one method for doing this, and that is by means of prisms. These should be from ½° to 3°, certainly not more than 4°, and their bases must be placed in. Beginning with the weaker prisms, the patient should look at the candle twenty feet distant for five seconds, during which time the guiding sensation has caused the externi to undergo contraction; and then the prisms should be held up for five seconds to allow relaxation to take place. These steps should be thus regularly repeated throughout each sitting of two to ten minutes, the sittings themselves being repeated from two to five times daily, as in treatment of exophoria. In suitable cases orthophoria can be brought about.

Hyperphoria.

Hyperphoria and cataphoria, like esophoria, are susceptible only to exercise by means of prisms. Given a case of left hyperphoria (right cataphoria) of not more than 1 ½°, there is a possibility of developing vertical orthophoria by means of rhythmic exercise. The muscle on the left side to be developed is the inferior rectus, and that on the right side the superior rectus. The prisms used should vary from ¼° to 2°—most cases will not require a stronger than a 1° prism. The base of the left prism must be up and that of the right down. As in exophoria and esophoria, the patient should exercise from two to ten minutes at a time, and two to five times a day. The object looked at should be twenty feet distant, and it should be seen through the prisms five seconds, then without the prisms five seconds, and so on throughout each sitting. Thus contraction and relaxation of the weak left inferior rectus and weak right superior rectus are effected in rhythmic order. If the hyperphoria is on the right side (left cataphoria), the base of the right prism must be up and that of the left down. In every form of heterophoria the angle of the prism must point in the direction of the muscle to be developed by it.

Occasionally cases present themselves in which there is a general weakness of the recti muscles, and especially of the external and internal recti, unaccompanied by general physical weakness. Such cases generally manifest esophoria for distance and exophoria in the near, neither muscle being able to overcome a prism of anything like the usual strength. To operate on such a case would be improper, since relief of the exophoria in the near would be attended by a corresponding increase of the esophoria for distance, and *vice versa*. In such cases the interni should be brought under the influence of the rhythmic exercise, as already set forth in our study of exophoria, at one time of the day; and, at some other time of the day, like attention should be paid to the external recti, as in simple esophoria. In these cases strychnia and electricity could be used with some promise of aiding the exercise treatment. Such patients should be allowed to undertake but little near work, until the exercise treatment by means of prisms has become well advanced. In these cases the wax taper treatment of the internal recti is not applicable until late in the course. These cases are far more stubborn than cases of simple exophoria and simple esophoria; and yet great advantage can be derived from the rhythmic exercise by means of weak prisms, aided by strychnia and electricity.

In cases in which the recti muscles are weak, because of a low state of general health, no treatment should be thought of except that intended for the well-being of the whole system. Use of the eyes in near work should be prohibited until recovery of the general health has occurred.

CYCLOPHORIA.

The treatment of insufficiency of the oblique muscles, as set forth in No. 1 of the current volume of the *Ophthalmic*

Record, is by means of cylindrical lenses (preferably convex), so placed as to lead the guiding sensation to demand contraction on the part of the weak muscles. The +1.50 D. cylinder is the most useful, but a weaker one may be used at the beginning. One should be placed before each eye; and if the weak muscles are the superior obliques, their axes must be placed in the lower temporal quadrant, at first 15° from the vertical, when, because of the slight retinal displacement of the object looked at, only a slight demand is made on the muscles, which should be kept up, in an intermitting way, for five minutes; then the axes should be revolved to 30° from the vertical, when, because of a greater displacement of the images, a greater demand for contraction is made on the part of the weak obliques, which should be kept up intermittingly for three minutes; now, lastly, the axes of the cylinders are revolved to 45° from the vertical, when the maximum displacement of the images occurs, and hence the maximum demand is made on the muscles, which should be continued intermittingly for two minutes only. As in the exercise of the recti by means of prisms, the best way to get contraction and relaxation alternately and in rhythmic order is to lower and raise the frames containing the prisms every five seconds; so, to get rhythmic contraction and relaxation of the obliques under exercise, it is best to lower and raise the frames containing the cylinders every five seconds throughout the sitting. It is unfortunate for the convenience of the patient that the relaxation of ocular muscles does not quickly follow the closing of the eyes, since it would be much easier to open and close the eyes every five seconds than to lower and raise the frames at the same interval. The oblique muscles relax much more readily than the recti on closing the eyes, but even these do not completely relax in the short time of five seconds.

In most cases of insufficiency of the obliques, exercising by means of cylinders once a day is usually sufficient. The best time for this exercise is before breakfast; the object looked at should be a wide lamp blaze fifteen to twenty feet distant. The cylinders should be properly centered. What prisms are to the recti, cylinders are to the obliques. In either case, the lenses correcting refractive errors should be worn during the exercise, in order that the best results may follow. The only exception to this rule is the wax taper exercise of the internal recti, when no lenses should be worn.

The expression " in suitable cases " has occurred frequently in this paper, and has been properly used. Its use implies that there are cases of heterophoria not suited to the exercise treatment. Such cases are numerous, and how to manage them is a most interesting question. The higher the degree of heterophoria, shown after a focal error has been fully corrected, the greater the necessity for operative interference, and the more extensive must be the operations. Given a case of exophoria of 10° in the near and 6° at a distance, we should attempt to correct the 6° by operations, effecting, as nearly as possible, half this correction by a partial tenotomy of one external rectus, and the balance by a partial tenotomy of the other, from three to six weeks later. To do more than this by means of the operations would be to develop some esophoria for distance, a thing not desirable; while to do less would be to run the risk of leaving so much exophoria that the rhythmic exercise, by means of the wax candle or by prisms, one or both, could not bring about orthophoria.

In still another case the exophoria might be so great that, after a partial tenotomy had been done on each external rectus, there remain a few degrees of exophoria for distance, so much that there can be no hope of curing by exercise. In such a case, instead of trying to effect more by repeating the operation on either one or both of the externi, one or both of the interni should be shortened. As in partial tenotomies, so in shortenings, it is better to divide the operation between the two corresponding muscles, for reasons long since given by Stevens. Having corrected all the exophoria for distance, falling only a little short or going only a little beyond, that remaining in the near may be relieved by the methods of exercise already set forth; but in no case should the exercise be commenced within six weeks after the last operation.

In relieving esophoria by operations and exercise the principles laid down for exophoria hold good, the operations on the muscles being reversed; and, too, the esophoria to be corrected is that determined by the near test, leaving the difference shown between the near and the far tests to be corrected by the rhythmic exercise of the externi.

In left hyperphoria of not less than 1½° nor more than 3°, this being as a rule the same for distance and in the near, some of it should be relieved by partial tenotomy of the left superior rectus and the balance cured by exercising the left inferior and the right superior recti; but if there is more than 3° of the vertical error, the operative effect should be divided between the superior of the left and inferior of the right, allowing an interval of not less than four weeks between the operations. Rather than over-correct, leave some of the original error for correction by the exercise.

As to cyclophoria nothing is applicable except the exercise by means of cylinders.

Whenever more than one of these muscular errors exist at the same time, all should be corrected by either exercise or operation, or both.

I have had made, for the convenience of my patients, three sets of exercise prisms; an exophoric set, an esophoric set, and a hyperphoric set. The box for each set is 6½ inches long, one inch wide, and 1½ inches deep. On one side, from end to end, there are five compartments of equal size for holding the five loose prisms. The remainder of the space in the box is for the frames, which should be of German silver, with No. 1 oval rims and a pupillary distance of 2½ inches. The grooves of the rims should be deep enough to hold readily the prisms; and the screws for confining the prisms should have a neck ¼ of an inch long, terminating in a milled head, so that the patient can readily remove one prism and put another in its place.

The "exophoric case" contains, in addition to the frames, one each of the following prisms: 1°, 2°, 3°, 4°, 5°, 6°, and 8°. These prisms are so cut that their bases can be placed out, as they must be in order to exercise the weak internal recti.

The "esophoric case" contains the following seven prisms: ½°, 1°, 1½°, 2°, 2½°, 3°, and 4°. These must be so cut that their bases may be placed in, as they must be in order to exercise the weak external recti.

The "hyperphoric case" should contain five prisms, as follows: ¼°, ½°, 1°, 1½°, and 2°. These must be so cut that their bases may be placed up and down.

The manner of placing these prisms, in an individual case, has already been set forth, as has also the method of exercise. As to method of exercise, a little more may be said. The prisms are not in pairs, because of the additional cost to the patient such an arrangement would involve. Taking an exophoric patient, I would place in the frames the 1° prism for one eye and the 2° prism for the other eye, bases out. I would have the patient exercise for five days, and then transfer the two prisms and exercise for five more days. At the end of this period I would have the 1° prism removed and the 3° prism put in its place, directing the patient to exercise with the new combination for five days, and then transfer the prisms and exercise through another period of five days. I would now remove the 2° prism and in its place put the 4° prism, directing the patient to exercise with the new combination for five days, at the end of which time I would have him transfer the prisms and exercise five days more. Now the 3° prism should be substituted by the 5° prism. This new combination should be used for five days, when a transfer of the 4° and 5° prisms should be made, to be followed by another five days of exercise. Now the 4° prism should be substituted by the 6° prism, and the exercise should be repeated as with the other combinations. At the end of this ten days the 5° prism should be removed and the 8° prism put in its place. From now on to the end of the treatment the 6° prism and the 8° prism should be transferred every five days. Whenever transfers are made or new prisms substituted, their bases must always be placed out, in the treatment of exophoria. Following the above plan, the exercise is continued for fifty days before reaching the strongest prism. With the strongest pair the exercise should be continued until the tests show that there is muscular balance, which may be in a few weeks or a few months. Because of the mild nature of this method of exercise, I am convinced that, for most persons, it is better than the method by means of the wax taper.

In using the esophoric set for the cure of esophoria, beginning with the weakest prisms, the strongest are reached in the same methodical way as in using the exophoric set, the only difference being that the bases of the prisms are placed in instead of out.

In using the hyperphoric set the same general plan as to time of exercise, the transferring and replacing of prisms, beginning with the weakest and finally reaching the strongest, should be observed. Always the base of the prism must be up for the hyperphoric eye and down for the cataphoric eye. Two or three sittings a day and ten minutes at each sitting is the correct practice.

The strength of every prism should be distinctly marked on its base, so that the necessary changes may be easily and accurately made by the patient.

To make the rhythmic exercise as easy as possible, I have had made an instrument for raising and lowering the frames. It is simple and can be readily made as follows: Take a piece of steel wire one-eighth of an inch in diameter and eight inches long; file it on two sides for a distance of one inch, until it is sufficiently thin to be bent somewhat in the shape of the neck of a goose, and fix the other end in a wooden handle about four inches long. The goose-neck extremity is made to grasp the shank of the frames on either side, between the rim and the temple piece, which it should fit sufficiently tight to hold the frames firmly. With handle in hand, the frames can be raised and lowered every five seconds without inducing fatigue of the arm.

Further experience, coupled with close observation, in developing weak internal recti muscles leads me to the conclusion that, for children who are exophoric, and in whom the ciliary muscle is strong, the wax taper exercise is the better of the two plans. The short time devoted to the taper exercise makes it well suited to children who would soon get impatient under the ten minutes rule with the prisms. For adults, especially those approaching middle life or beyond it, in whom the muscle of accommodation is not so strong as in children, the prism exercise is better. Understanding the reasons for the exercise, the adult willingly comes under the ten minutes rule.

Since the publication of this chapter on "Rhythmic Exercise the Proper Method of Developing the Ocular Muscles," I have adopted a modification of the method, as to exophoria, set forth therein, but resort to it only after the original method ("fixing" only a lighted candle or gas jet at fifteen to twenty feet) has been practiced for from two to four or more weeks. Briefly it is this: The patient must be seated from fifteen to twenty feet from the lighted candle or gas jet, and must have in one hand a white card on which is a cross or a dot. With the prisms on, the patient must look first at the distant blaze for about two seconds; then at the dot on the card, held at the reading distance, for about two seconds; then at the blaze again for two seconds, when the frames containing the prisms should be elevated for five seconds, during which time the vision is kept fixed on the blaze. Now lowering the frames, the patient continues to look at the blaze through the prisms for two seconds; then at the dot on the card as before for two seconds, and again at the blaze for two seconds, when the frames are again elevated for five seconds, the patient continuing to look at the blaze, thus allowing the internal recti to fully relax. The procedure is again repeated, and so on to the end of the sitting—ten minutes. This modification is a little complex, but patients can be readily taught how to resort to it. I am convinced that it will add greatly to the rapidity of the cure.

As the treatment advances, the prisms should be shifted and replaced as already set forth in this chapter.

CHAPTER VIII.

STHENIC AND ASTHENIC ORTHOPHORIA, AND STHENIC AND ASTHENIC HETEROPHORIA.

THERE is such a condition as lateral orthophoria, in which neither the interni nor externi are sufficiently strong. There is also such a condition as vertical orthophoria, in which both the superior and inferior recti are weak. Of the former we had something to say at the last meeting of the American Medical Association (Baltimore, 1895); we have known of the existence of the latter since November, 1895. Since there are two kinds of orthophoria, it seems necessary to have terms for distinguishing them. Sthenic orthophoria would aptly describe the form in which the muscle balance is in strength; while asthenic orthophoria would apply to that form in which the muscle balance is in weakness. It is evident that only asthenic orthophoria should receive any consideration, from a therapeutic standpoint.

As there are two kinds of orthophoria, there are also two forms of heterophoria, the sthenic and the asthenic, the one being easily distinguishable from the other, and each requiring its own proper therapeutic procedure.

STHENIC ORTHOPHORIA.

This condition is not often encountered, though it occurs more frequently than the asthenic form. In lateral orthophoria of the sthenic type the externi are found to balance the interni in both the far and the near tests, and abduction is 8° or more. These conditions found, there is no need for testing the adduction, nor does there exist an indication for the application of any therapeutic law to the lateral ocular muscles.

Sthenic orthophoria as applied to the vertically acting muscles is determined by the balancing of these muscles in the distant test, associated with a deorsumduction of 3° or more. This condition, when found, cannot be made better, for it is already perfect.

ASTHENIC ORTHOPHORIA,

as applied to the lateral muscles, manifests itself by a low abduction (less than 8°) associated with a balancing of these muscles in both the far and the near tests. Finding the externus weak, although capable of balancing its opposing muscle, it at once appears that the internus, too, must be weak. The lower the abduction in this condition the worse is the case. We have at our command two methods of treatment, either one of which, or both combined, will bring great relief to the patient. The first method consists of prismatic exercise of both the interni and the externi. The most convenient arrangement of such prisms is that suggested by Dr. George H. Price about two years ago—viz., prisms put in ordinary spectacle frames like Franklin divided lenses, the upper prisms with bases in, the lower with bases out. Since the indication, in lateral asthenic orthophoria, is to add equally to the tonicity of the externi and the interni, the prisms in the upper part of the rim should be of the same strength as those in the lower. The objects to be looked at during the period of exercise should be a candle, lamp or gas jet placed twenty feet from the patient, and a card with a dot or cross mark on it to be held in the hand. Viewing the light through the upper prisms, the externi are made to contract, so as to effect binocular single vision; while looking at the mark on the card through the lower prisms calls into action the interni. The light and the dot are fixed alternately every five seconds, and thus is excited rhythmic contraction and relaxation of the lateral muscles. The exercise should be continued five or ten minutes, and should be repeated twice or oftener in the twenty-four hours. The prisms used need never be stronger than 4°, and, as in the heterophoric condition, it would be better to commence with weaker prisms.

The other method of exercising these muscles is the synchronous moving of the eyes in the horizontal plane to the right and left alternately, fixing for only a moment some object previously placed on the wall for the purpose. Since this will usually be done in a room, it might be named the "wall-to-wall" exercise. The point of view should be changed from side to side every few seconds, and the exercise should be continued five to ten minutes, but should always be stopped short of fatigue. Two ways of modifying the treatment in the beginning, so as not to excite fatigue, would naturally suggest themselves: the one looking far to the right and left for only a short while; the other looking only a little way to the right and left for several minutes. In the one, the time should be increased gradually; in the other, the arc to be described by the visual axes must be extended gradually to the utmost capacity of the binocular sweep. In any case, either method alone would serve to add strength equally to the muscles exercised; both methods might be combined in any case with profit, the patient being directed to resort to the wall-to-wall exercise every morning and the prismatic exercise in the evening. As the treatment progresses, the abduction should be tested at intervals of a few weeks, and when this reaches 8° there is no further indication for treatment.

Asthenic Vertical Orthophoria

was first noticed by the writer in November, 1895. The first patient was astigmatic, and had slight exophoria in the near, with abduction of 8°. There was no hyperphoria. Her focal error was corrected and her exophoria in the near responded readily to rhythmic exercise. Her eyes were still incapable of comfortable near work, for which there seemed to be no explanation. A statement by the patient divulged the secret of her trouble. She said that if she should hold a book or paper on a level with her eyes she could read with a fair degree of comfort. It at once appeared that, while there was vertical orthophoria, there was nevertheless weakness of the superior and inferior recti of both eyes. The strength test confirmed the suspicion, for her sursumduction and deorsumduction were less tuan 1°. Looking either up or down was fatiguing. The condition found, the remedy was at hand in the

Ceiling-to-floor Exercise

of the superior and inferior recti. The patient was directed to stand near one wall of a room of usual size, and to select some mark on the ceiling near the opposite wall for upward fixation, at the same time placing a piece of coin, a thimble, or some other object on the floor four feet in front of her for downward fixation. Standing erect, with head set as for vision straight ahead, she was directed to look at the chosen mark on the ceiling for a moment and then at the object on the floor, alternating from the one to the other every two or three seconds, for a length of time short of fatigue. She was directed to repeat the exercise two or three times a day, never longer than ten minutes at a time. Her improvement began at once, and has progressed satisfactorily. Within two weeks her sursumduction and deorsumduction were 2°. There can be no doubt that her improvement was a *propter hoc* and not a *post hoc*. The treatment was rational; it proved efficient. Several similar cases of less severity have been observed since the first one, and have been benefited by the ceiling-to-floor exercise.

Prismatic exercise of the superior and inferior recti could be easily resorted to, the prisms being of the same strength, their axes vertical and their bases toward each other in the rims, after the style of the Franklin divided lenses. By slightly elevating and lowering the frame, the patient could be made to look at a light across the room alternately through the upper and lower prisms. This raising and lowering of the frames should be rhythmic. The prismatic exercise cannot surpass, if equal, the ceiling-to-floor exercise.

Asthenic vertical orthophoria may coexist with a similar condition of the lateral recti muscles, and often does complicate an asthenic exophoria. In either case a part of the treatment should be a combination of the ceiling-to-floor and the wall-to-wall exercise, changing from the one to the other every half minute or minute, thus continuing for ten or more minutes.

Sthenic and Asthenic Heterophoria

are not products of the imagination, but they have an actual existence, the importance of which, from a therapeutic standpoint, should not be ignored. To confound them in diagnosis is to err in treatment.

Sthenic Exophoria

is a common condition, and may be readily determined. The phorometer shows exophoria in both the far and the near tests: and abduction is 8° or more. The plan of treating these cases must be decided upon after carefully weighing the results obtained by both the phorometer and the abduction. However great may be the exophoria far and near, if the abduction is 8°, nothing should be done to the externi. A partial tenotomy would do harm, and any exercise of these muscles would only increase the trouble. Attention should be given only to the interni. Much may be accomplished by rhythmic exercise, by means of the exorphoric set of prisms; or by looking at a lighted wax candle as it is moved from arm's length to within six inches of the eyes, following this at once by looking at some distant object, repeating the process several times at each sitting; or by the method of using strong prisms, advocated by Gould. The success of either of these plans, or of all combined, will depend on the quantity of the exophoria and on the age of the individual patient: the smaller the error and the younger the patient, the more rapid will be the cure. Failing to cure with the exercise, only one thing remains to be done—viz., shortening or folding one or both interni. After this operation, if a small part of the old error remains uncorrected, the exercise treatment may be resumed with the prospect of completing the cure.

If, in a case of sthenic exophoria, the abduction is more than 8°, another indication for treatment presents itself. This indication is for a partial tenotomy of one or both externi, and this should be done without temporizing with any method of exercising the interni. The operation should be so carefully done as never to reduce the abduction below 8°. Often a partial tenotomy of both externi will produce the desired result, the establishment of sthenic orthophoria. Failing in this, rhythmic exercise of the interni will complete the cure in many cases, though occasionally the interni must be strengthened by shortening one or both. In the management of these cases we have at our command partial tenotomies of the externi, rhythmic exercise of the interni, and shortening of the interni.

Asthenic Exophoria.

In this condition the phorometer will show exophoria, in the far and near tests, assciated with abduction less than 8°. In these cases the abduction sometimes falls as low as 3°, and frequently will be as low as 5° or 6°. In the management of these cases a partial tenotomy of the externi can do only harm, and the shortening of the interni is of doubtful propriety. The former operation will never have to be done; the latter may become necessary, but in these cases it becomes a matter of great delicacy. Two methods of exercise should be resorted to daily in these cases, their conjoined use promising the greatest good. The first is rhythmic exercise of the interni by means of the exophoric set of prisms; the second is the wall-to-wall exercise of both the interni and the externi, as advised for the management of asthenic orthophoria.

In the beginning of our study of this condition two years ago, the patient was directed to place the prisms for exercising the interni at one time in the twenty-four hours, and at another time placing them for the exercise of the externi. Out of this method grew Dr. Price's double prism arrangement for exercising all the lateral muscles at the same sitting. This is a device of no mean merit.

It was, doubtless, in cases of asthenic exophoria that Dr. Park obtained his good results from having his patients look from side to side, as set forth in his paper read before the Section of Ophthalmology, A. M. A., at Baltimore, May, 1895. Certainly this method could do no good in cases of sthenic exophoria.

STHENIC ESOPHORIA

is not so common as sthenic exophoria. The phorometer shows esophoria in the far and near tests, and the adduction is 40° or more. While partial tenotomies of the interni may become necessary in order that these cases may be cured, other means ought first to be tried, except in cases with a high degree of the error. The other available means are: First, the full correction of a coexisting hypermetropia, with or without astigmatism, thus curing the pseudo-esophoria; secondly, the rhythmic exercise of the externi by means of the esophoric set of prisms. This failing, a partial tenotomy of the interni should be done, if adduction is above the normal, while shortening of the externi should be done if adduction is only normal. After either of these operations has been done, if only a small quantity of the original error remains, the cure may be completed by rhythmic exercise of the externi. In the higher errors, the operator may have to perform a partial tenotomy on both interni, and make a shortening operation on both externi, and then find something for rhythmic exercise to accomplish.

Asthenic Esophoria.

In this the phorometer shows esophoria in the near and far tests, and the adduction is below normal. In discussing sthenic esophoria we have placed the normal adduction power at 40°, which cannot be far from right. The adduction in asthenic esophoria may drop as low as 20°, but in most cases that have been observed it has been between 30° and 40°. A low adduction in esophoria is necessarily associated with very low abduction, which should be tested. The treatment of this condition should be by means of gymnastic exercise alone, at least for a long while; and at no time should an operation on the interni be considered. Each of two kinds of exercise should be resorted to once or twice a day. The externi should be exercised by the esophoric set of prisms, and both the externi and interni should be exercised by the wall-to-wall method. These failing to accomplish all we would desire, a shortening of one or both externi should be done. The object of the shortening would be the production of asthenic orthophoria, which must be cured by the wall-to-wall exercise or by means of the double prisms. In asthenic esophoria, a partial tenotomy of an internal rectus would result in harm, and should never be done.

Sthenic Hyperphoria.

In this the phorometer shows the hyperphoric condition to exist, and measures its quantity. There is in these cases a sursumduction of the hyperphoric eye and a deorsumduction of the cataphoric eye of 3° or more. In those cases in which the sursumduction of the hyperphoric eye is only 3°, the normal, the treatment should be by exercise alone, to be accomplished by the use of the hyperphoric set of prisms. A tenotomy of the superior rectus of the hyperphoric eye would give quick, but temporary, relief; but if an operation is to be done at all in these cases, it should be the shortening of the inferior rectus of the hyperphoric eye. A muscle that has only the normal amount of intrinsic strength, as shown by the duction test, should be allowed to retain it.

In cases of sthenic hyperphoria with sursumduction of more than 3°, the first indication is a partial tenotomy of the superior rectus of the hyperphoric eye, but it should be done so as not to reduce its duction power below the normal. If there still remains a good deal of hyperphoria, and the deorsumduction of the cataphoric eye is 4° or more, a partial tenotomy of its inferior rectus may be done, but it would probably be better to do a shortening operation on the inferior rectus of the hyperphoric eye. One or more operations having been done, whatever hyperphoria may remain should be cured by means of the hyperphoric set of prisms.

Asthenic Hyperphoria

is a very common condition. The degree of hyperphoria shown by the phorometer is not great, rarely more than ½°, while the sursumduction of the hyperphoric eye and the deorsumduction of the cataphoric eye are below the normal, often as low as 2°, and sometimes not being more than 1°. Only exercise of the superior and inferior recti should be considered in these cases. Each of two methods should be resorted to once or twice a day. At one sitting the inferior rectus of the hyperphoric eye and the superior rectus of the cataphoric eye should be exercised by means of the hyperphoric prisms; the next exercise should be of all the vertically acting muscles by means of the ceiling-to-floor method. The object of the prism exercise is to develop the condition of asthenic vertical orthophoria, while the aim of the ceiling-to-floor exercise is to convert the asthenic into sthenic vertical orthophoria.

Esophoria in the far and exophoria in the near is always an asthenic condition, and should be treated by prismatic exercise and by the wall-to-wall method. The prism exercise should be by means of the Price double prisms, those above to be half the strength of those below. The aim in view, when using the prisms, is the development of asthenic lateral orthophoria, while the wall-to-wall exercise is to convert the asthenic into sthenic orthophoria. No operation should ever be done on these cases.

CHAPTER IX.

CAN PRESBYOPIA BE DEFERRED BY RHYTHMIC EXERCISE OF THE CILIARY MUSCLES?*

One of two conditions, or possibly the two combined, constitute the causation of old sight: the one, loss of ciliary power; the other, loss of elasticity of the crystalline lens. That either of these conditions existing alone could cause old sight none can doubt; that the two conditions coexist in well-advanced cases is a matter easily believed. Lost elasticity of the lens would lead to inactivity, and consequent atrophy, of the ciliary muscle; while diminished or lost ciliary action would cause suspension, if not loss, of lens elasticity.

That the leading cause of old sight is failure of ciliary power we think may be proved; and if this is true, simple and scientific means for deferring the onset of presbyopia may be brought into use. Rhythmic exercise can be as readily effected in the ciliary muscle as in any of the extra-ocular muscles. Will this exercise develop the power of these muscles that are under the direct control of the *guiding sensation*, the common master of all the extra- and intra-ocular muscles?

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*Read in the Nashville Academy of Medicine January, 1894.

That involuntary muscular fibers can be increased in size and augmented in power, as a result of effort to overcome obstruction, is a matter of common acceptance, so far as the heart and bladder are concerned. In mitral stenosis it is well known that the walls of the left auricle become hypertrophied and more powerful, so that it may send the blood through the narrowed opening into the ventricle; in like manner, when there is obstruction at the aortic opening, the walls of the ventrical become hypertrophied and more powerful.

When the prostate gland is enlarged or there is stricture of the urethra, impeding the flow of urine, the muscular fibers in the walls of the bladder are increased in size, and become much more powerful, so as to be able to force the flow. It will be conceded that this muscle development in heart and bladder results from *effort* to overcome obstruction.

Displacement of images by prisms and blurred images by means of concave lenses are obstructions which, if not too great, will be overcome by muscular action, the former by action of the recti muscles, the latter by action of the ciliary muscle. Many observers have already acknowledged that rhythmic exercise of the recti muscles, by means of prisms, and of the obliques by means of cylinders properly placed, not only increases their power, but at the same time dispels the nervous phenomena associated with and dependent on their former weakness. If the ciliary muscles can be developed by rhythmic exercise, then concave lenses, not too strong, used rhythmically, but not too long at a time, may be the means of deferring old sight to five or ten, or even more, years beyond the now common age of its onset—about the age of forty-five years.

As in developing the recti and oblique, so in the development of the ciliary muscles, the power to overcome obstruction should never be taxed to anything like its fullest capacity. Gentle contraction and relaxation, rhythmic in order, continued five to ten minutes and repeated two or three times in the twenty-four hours, must result in giving tone to the ciliary muscle. The time of life for beginning the exercise, and the strength of concave lenses to use, are matters that must be settled by observation and experience. As a preliminary to the treatment of failing accommodation, all existing focal errors should be corrected, and this correction should be worn behind the exercise lenses at each sitting. It is my present judgment that —.50 D. spherical lenses, properly centered, will be the most useful. The patient should be seated fifteen to twenty feet from a lighted candle, lamp or gas jet, and should look at the same through the concave lenses five seconds, and then raise them for a period of five seconds, and so on to the end of the sitting. It is evident that, with the focal correction on when needed, the image of the flame is sharp, satisfying the guiding sensation without ciliary action. The moment the weak concave lenses are lowered the image is blurred, and at once the ciliary muscle is called into action, to again return to a state of rest the moment they are raised. Thus contraction and relaxation are easily induced. In this way the nutrition of the muscle should be improved and its power enhanced or maintained. The age at which to begin the exercise, as a rule, need not be under forty nor over forty-three years, and it should be continued as long as the proper reading distance is preserved.

The question would naturally arise in the mind of the patient as well as that of the practitioner, "Can any injury come from the treatment?" The nutrition of the ciliary body is from the blood that circulates in it. Nothing is more reasonable than that gentle, rhythmic, and periodic exercise of the ciliary muscle would improve the nutrition of the ciliary body, just as the nutrition of other muscles is improved by proper exercise. No harm, then, could come to the *muscle* as a result of the proposed gymnastic exercise. May we fear unfavorable change in the lens as a consequence of this exercise of the ciliary muscle? It is generally conceded that the lens gets its nourishment, by the process of osmosis, from the blood circulating in the ciliary body. It must be acknowledged that the better the nutrition of the lens, the more likely will it retain its two very important properties, transparency and elasticity. It cannot be denied that the better the nutrition of the ciliary body, the healthier will be the crystalline lens. We must conclude that, if the exexcise would improve the condition of the ciliary body, it would at the same time have a tendency to improve the nutrition of the lens, whereby the latter would be only the more certain to continue both transparent and elastic. Thus not only may old sight be deferred, but also the development of cataract may be prevented. .

May there not be such a condition as congenital weakness of the ciliary muscle? If so, have we not, in the proposed rhythmic exercise, by means of concave spherical lenses, a source of power to the weak muscles?

Since reading the above paper before the Academy of Medicine, continued observation and experience have so far been confirmatory of the correctness of the thoughts contained therein. As to the last paragraph of the paper, I am sure that there is a great deal more in it than I thought there was at the time it was penned. Not only may there be a congenital or an acquired weakness of both ciliary muscles, but there are undisputed cases of greater weakness on the part of one muscle than on the part of the other in the same pair of eyes. For instance, one eye may have an accommodative power of 4 D., while the other, under simlar tests, would show an accommodative power of 5 or more D.

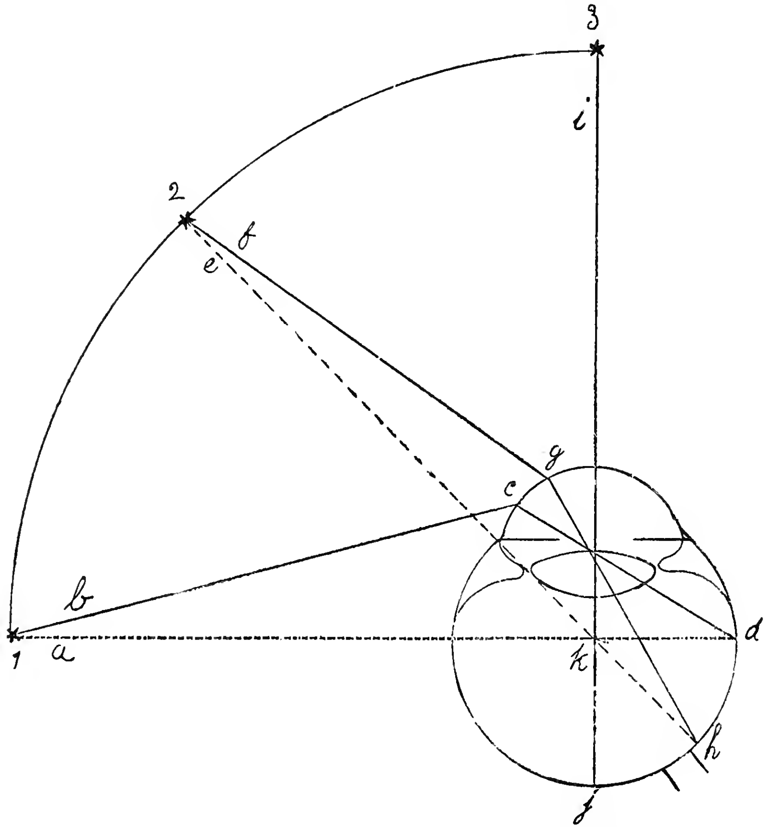
When there is a similar want of power in the two muscles they both should be exercised at the same time after the method set forth in the paper. If there is a difference in the power of the two muscles, the eye having the stronger muscle should be covered while the other muscle is exercised by means of the concave sphere.

If any case of hypermetropia associated with exophoria is more comfortable by wearing the convex glasses correcting same, that of itself is an evidence of either a congenital or an acquired weak condition of the ciliary muscles. These cases are sometimes, though rarely, met with. Such a case furnished with concave glasses to be worn continuously, as is sometimes done by opticians, would be made worse and not better; while if the ciliary muscles were stronger, the concave glasses making the case more hypermetropic, but at the same time lessening the complicating exophoria, would bring relief to the patient.

CHAPTER X.

THE LAW OF PROJECTION AND THE ARTIFICIAL AND NATURAL CAUSES THAT MODIFY IT.

In the March (1893) issue of the *Ophthalmic Record* I announced what I believed to be the law of projection in the following words: "What is true of one part of the retina, as to projection, must be true of all parts. In the field of vision, that object is most distinctly seen which is on the line of the visual axis and consequently throws its image on the yellow spot. The visual axis is a line *vertical* to the yellow spot." By the aid of the accompanying cut I propose to show that the law of projection is this: *Every object seen must be on a line vertical to that part of the retina receiving the impress of the light, regardless of the direction of the axial ray in the eye.* In the cut, the star-shaped Figures 1, 2, and 3 represent sources of light. The eye is represented as being fixed on Figure 3, from which extends the line *i* through the eye to the macula lutea. This line represents the coinciding visual axis and the central ray of the cone of light, and is conceded to be vertical to the retina at this point. While the vision is fixed on Figure 3, Figure 1, which is 90° from Figure 3, makes it impress on the nasal side of the retina 90° from the macula. That Figure 1 may be seen at all it must send rays of light through the cornea and



pupil into the eye. The incident ray is *b c*, while *c d* is the refracted ray (for convenience of study the combined refraction of the cornea and the lens may be represented as taking place at the corneal surface). Its impress is made on the retina at *d*. In obedience to the law, the source of the light is projected on the line *a d*, which is vertical to the retina at *d*. In the same manner, as is shown in the cut, Figure 2, to be seen, must send light through the cornea and pupil into the eye, that it may make its impress on the retina. The incident ray is *f g* and the refracted ray *g h*. The source of the light is at once projected on the line *c h*, which is vertical to the point of the retina at *h*. As is shown in the cut, the three lines of direction (projection) cross one another in the center of retinal curvature, and are therefore radii prolonged.

In the perfect eye all that we claim for the macula lutea, as to projection, must be granted. This being granted, it can be easily made clear that all points of the retina obey the same law of projection. The arc *1–3*, on which are located the three sources of light, and the retinal arc *j d*, on which the images of these objects fall, are each 90°, and parts of concentric circles, the common center being at *k*. Since objects are seen on straight lines, and Figure 1 is at a right angle to Figure 3, its image on the retina at *d* must be just 90° from *j*, the macula, where falls the image of Figure 3. Thus we can understand how objects situated on any part of the arc *1–3* must throw their images on corresponding points of the retinal arc *j d*. If further confirmation were needed, we have it in the fact that, when the eye sees two lights, represented in the cut by Figures 3 and 1, if the visual axis is made to sweep the arc from Figure 3 to fix on Figure 1, while the attention is fixed on Figure 3, the latter is not seen to move, thus showing that every part of the retinal arc (from *j* to point of retina cut by line *a d*) over which the image of Figure 3 has passed, obeys the same law of projection as that governing the macula.

From the above reasoning we deduce the following conclusions: The line of direction is a prolonged radius of retinal curvature; the center of direction *k* is the center of retinal curvature; the visual angle is located at *k*, and is unalterable in position, but may be changed in size by properly centered convex and concave lenses; the visual angle being nearer the retina than formerly supposed, retinal images must be correspondingly smaller; on either side of the visual axis, the incident and refracted ray, with the line of direction as a base, form a triangle, the apex looking toward the visual axis, the angle at the apex growing larger as the source of the light approaches the visual axis.

That the law of projection is susceptible of modification by conditions that may be brought into existence artificially, and by at least two natural conditions, cannot be denied. Other laws of nature are subject to similar modifications. In obedience to the law of gravitation, everything within the range of the influence of the earth is drawn toward its center. If other forces could not modify the law of gravitation, all objects on the earth would be fixed, and any object in the atmosphere would be drawn toward the earth in a straight line. If a ball be allowed to drop from the hand, it goes in a straight line to the earth; if it be thrown by the exercise of the muscular power of the arm, it must come to the earth, but in doing so it describes a curve. The muscular force has thus modified the law of gravitation.

The modifications of the law of projection take place only where there are *two* eyes. With a lighted candle twenty feet distant, one eye may be closed while the other is fixed on the blaze. Interposing a prism of 6°, base out, before the open eye, the candle is displaced toward the opposite side, where it can be readily fixed by a contraction of the internal rectus shifting the visual axis; but the line of projection remains vertical so long as the fellow-eye remains closed. On opening the other eye two candles are seen, but they immediately run into each other, in obedience to the law governing the recti muscles, causing them to so act as to place the macula in each so that it may receive the image of the candle. In this case the line of projection of the eye before which the prism is held does not pass through the center of direction, *k*, but on the temporal side of it. Remove the prism, and at once the law of projection reasserts itself. The sensorium is so influenced by the disturbing element (the prism) that, at one trial, both lights seem to move toward each other; at another trial, the true candle appears to move to the false; and again the false to the true candle. It is, at the same time, evident that the line of projection is displaced only in the eye before which the prism is held. By reversing the prism the line of direction can be made to pass on the nasal side of the center of direction, *k*.

In a similar way it can be shown that cylinders placed before non-astigmatic eyes obliquely in opposite directions, or, if in the same direction, more obliquely before one eye than the other, cause a modification of the law of projection. In the case of prisms, the modification of the law of projection is effected by the contraction of the recti in fusing the images; in the case of the cylinders, the contraction of the obliques, for the purpose of fusing the images, causes the modification of the law of projection.

Prisms and cylinders constitute the two *artificial means* that disturb the law of projection. Decentration of the macula in, out, up, or down, but in opposite directions in the two eyes, or if in the same direction, the one being decentered more than the other; and oblique astigmatism, the obliquity being in opposite directions, or if in the same direction, more oblique in the one eye than in the other, constitute the two *natural means* that disturb the law of projection.

Any condition disturbing the law of projection is an undesirable thing, and should be remedied. In cases where there is decentration of the maculæ, the law of projection can be given full play only by means of correct prisms properly placed; likewise in oblique astigmatism the majesty of the law can be asserted only through the means of correcting cylinders properly placed. In determining both of these conditions the ophthalmometer is invaluable.

Have we not in this an explanation why, in some cases of heterophoria, prisms are a source of much comfort, while, in other cases, they add to the discomfort? In the light of the reasoning had, it seems clear that when the maculæ are properly centered, whatever form of heterophoria may exist, be it of high or low degree, it would not be wise to attempt its relief by means of prisms. Prisms should be prescribed for that form of heterophoria only where there is evidence of decentration of the maculæ.

Again, the law of projection as herein announced settles the question of corresponding parts of the two retinæ. If the two visual axes be fixed on an object, it can be demonstrated that another object on the monoscopter, to the right, will throw an image on the nasal half of the right retina the same distance from the macula as the image in the left eye will be from the macula on the temporal half of the retina. In each case the object will be projected on lines vertical to the parts of the two retinæ receiving the impress. These lines of projection, intersecting at the object, make it appear as *one*. The same can be demonstrated as true of any object situated on the monoscopter.

The law of direction, as herein given, affords us a satisfactory and scientific answer to the question: Why is it we see objects erect when we know their images are inverted on the retina? A line drawn from a man's head to the center of the observer's eye, when prolonged, must strike the retina as many degrees below the horizontal plane of the center of direction as the head of the observed is above this plane; and in like manner a line drawn from the man's feet through the center of the observer's eye, when prolonged, must strike the retina at a point as many degrees above the horizontal plane as the man's feet are below this plane. The rays of light from the head and feet, though not coincident with the lines of direction, after being refracted make their impress respectively on those parts of the retina which we have already pointed out as being connected, by straight lines passing through the center of direction, with the head and the feet. In obedience to this law we see the sides of the object the reverse of those of the image.

Binocular single vision, and erect objects and inverted images, result from this physical law: Every object seen must be on a line vertical to that part of the retina receiving the impress of the light.

CHAPTER XI.

THE MONOSCOPTER.

We have both a line and a surface of binocular single vision. The term used by those authors who speak of it at all is "*horopter*," which means limit of vision. Noyes is the only one of the several writers on ophthalmology in my possession who speaks of the horopter. In speaking of it he says: "The *horopter* is a line which represents the curve along which both eyes can join in sight, and it is formed in this way: As the eyes fix on a given object far to the left side, and move far to the right at the same inclination of the visual lines, they form a triangle whose apex, as it passes from left to right, forms the horopter curve for this plane. If the movement be in any other plane, vertical or oblique, the horopter will be formed in the same way for that plane. In its simplest form, as explained by Johannes Mueller, it is a circle which passes through the center of rotation of each eye, and through the apex of the point of fixation of the visual lines." If it be granted that, by the expression "centers of rotation," Mueller meant the centers of retinal curvature, then all that has been quoted above can be demonstrated as true mathematically; and yet Noyes, in closing the paragraph, says: "This statement [of Mueller] is not strictly correct, but will suffice for our purposes." Noyes's statement and that of Mueller are exactly the same in substance.

Before entering into the demonstration of the line and surface of single seeing, which I shall name the *monoscopter* (μονος, single, and σκοπεων, seeing), a name chosen after a consultation with Prof. George W. Jarman, who has taught Greek for many years, I will quote Noyes a little further: "If the back of the eyeball be divided into quadrants by vertical and horizontal planes whose intersection shall be at the fovea centralis, and parallel to these lines we mark points one tenth of a millimeter asunder, and then suppose the two retinæ to be superimposed upon each other so that the vertical and horizontal lines shall exactly coincide, the points we have imagined will of course also coincide. The coincident points, which are equidistant from the center, are spoken of as correspondent points of the two retinæ."

What I have quoted from Noyes could not be true if the law of projection, as published in No. 12, Vol. II., of the *Ophthalmic Record*, were not the truth.

Believing that I have already demonstrated* that the law of projection (direction) is, "Everything seen is on a line vertical to the part of the retina receiving the impress of the

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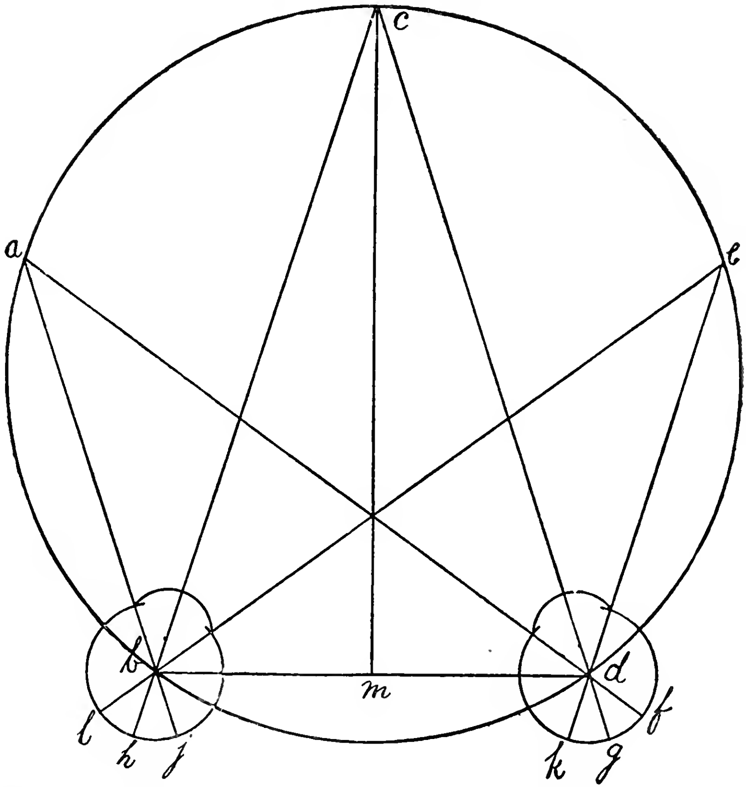
*See Chapter X.

light" (all lines of direction cross at the center of retinal curvature), I will now demonstrate the

MONOSCOPTER.

By reference to the accompanying cut, it will be seen that



the three points chosen for the construction of the circle are: *c*, the point of fixation of the two eyes; *b*, the center of retinal curvature of the left eye; and *d*, the center of retinal curvature of the right eye. This line of single seeing is in the plane of the visual axes. A point situated anywhere on this line, capable of sending rays of light into the two eyes, must be seen as *one* by the two eyes. The visual axis, *h c*, and the visual axis, *g c*, intersect at *c*, therefore the point *c* must be seen as *one*. Point *a* on the circle sends rays of light (not shown in the cut) into both eyes. Those in the right eye strike the retina at *f*; those in the left eye, at *j*. The visual line *a j* passes through the point *b*, and the visual line *a f* passes through the point *d*. Since these visual lines intersect at *a*, then this point must be seen as *one*. As is seen, *j* and *f* are in the same plane. It can be proven that *j* is just as far on the nasal side of the yellow spot *h*, as *f* is on the temporal side of the yellow spot *g*. Since the angle *a b c* is equal to the angle *h b j*, and the angle *a d c* is equal to the angle *g d f*, it only remains to prove that the angle *a b c* = the angle *a d c*, in order that it may be shown that *j* and *f* are correspondent parts of the two retinæ. The angle *a b c* (an inscribed angle) is measured by half the arc *a c*; the angle *a d c* (an inscribed angle) is measured by half the arc *a c*. Since the two angles *a b c* and *a d c* are each measured by half the same arc, *a c*, the one must be equal to the other. Thus is proven the correctness of Mueller's definition of what he improperly called the *horopter*.

Having proven the *line* of binocular single seeing, it is easy enough to demonstrate the *surface* of single seeing, which is a *surface of revolution*, described by revolving the circular plane *a b d e c* on its cord *b d*, while the eyes remain stationary. This surface is a combination of a concave sphere and a concave cylinder.

My private student, Dr. Manning Brown, succeeded in having constructed for me this peculiar concave surface.

It is interesting to note, further, that all angles formed by the intersection of visual lines in the monoscopter are equal to one another. The angle *b a d*, formed by the visual *lines* *b a* and *d a*, is equal to the angle *b c d*, formed by the visual *axes* *b c* and *d c*, for each is measured by half the arc *b d*. What is true of these two angles is true of any angle formed on the monoscopter by the intersection of visual lines. Thus is proven to be correct the statement quoted from Noyes in the beginning of this demonstration, if he meant, by the expression "same inclination of the visual lines," that the angle formed by the intersection of the visual axes remains the same, as the curve is being described.

PART II.

Contributions to Old Studies.

CHAPTER I.

HETEROPHORIA: AND A SAFE LINE DRAWN BETWEEN OPERATIVE AND NON-OPERATIVE CASES; AND THE AUTHOR'S METHOD OF OPERATING.

Of the several theories held by different observers as to the nature of heterophoria, neither one may be absolutely correct to the exclusion of the others. In some cases one theory may be correct; in other cases, another theory; and in another class of cases, a still different theory would be applicable.

A brief review of the different explanations of heterophoria may not be out of place just here. One view is that there is a congenital feebleness of one muscle as compared with its opposing muscle, this weakness being due either to the fewness of the muscular fibers entering into its formation or to its faulty attachment to the sclera, this in the weak muscle being abnormally far from the corneo-scleral junction, or to a want of proper innervation. That there can be truth in this view no one can successfully deny. There can be no case of heterophoria in which this theory will not explain some of the phenomena.

Another theory denies that heterophoria is congenital. Its advocates teach that the development and growth of the ocular muscles have been normal, their attachments perfect, and their nerve supply all that could be desired. They would teach us that some irritation in or about the eye, or in some organ remote from the eye, excites a spasm, tonic in its nature, in one of a pair of muscles, thus destroying their harmonious action. This spasm existing in the superior rectus would give hyperphoria; in the internal rectus, esophoria; in the external rectus, exophoria: in one of the obliques, a form of heterophoria first described by the author of this paper.* [To this condition my office associate, Dr. George H. Price, has since applied the name Cyclophoria.] This condition would certainly explain some of the phenomena seen in the examination of any case of heterophoria, and will, therefore, always have its advocates.

The third theory grants that congenitally the muscular apparatus of the eyes may be all right, just what is claimed by the advocates of theory No. 2; and yet it claims that the

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* See *Archives of Ophthalmology*, Vol. XX., No. 1, 1891.

cause of heterophoria is congenital, in that the maculæ do not occupy corresponding places in the two retinæ. A congenital displacement of the macula up or down in one eye would give hyperphoria; a congenital displacement of the macula in one or both eyes, outward, would give esophoria; and a similar displacement inward would give exophoria. This theory also includes the idea that an abnormal placing of the eyes in their orbits can cause heterophoria. If one eye (and its orbit) occupies a lower plane than its fellow, there necessarily results a hyperphoria.

If any other theories for heterophoria have been framed, they have not come under my observation. Only two of these theories have before been published so far as I know. The third theory being a deduction of my own, and is here given for what it may be worth.

Something can be said for and against all of these views. Against all of them stands the one fact that, in many cases of horizontal heterophoria, we have esophoria for distance and exophoria for near.

If asked which of the three I accept, I would answer that I believe that each one contains a germ of truth; and that, possibly, the conditions included in each coexist in certain cases.

There may never be unanimity of opinion as to the nature of heterophoria; but the concession that such a thing exists is already universal. Heterophoria, having always had an existence, will always continue to exist. In the not very remote past nothing was done for its relief, because nothing was known of its existence. Oculists of to-day and of the future must combat this disturber of human comfort.

In order to reach a conclusion as to the form of heterophoria, and the amount of same in any given case, and how it should be dealt with, two or more of the several tests now known should be resorted to. In all cases it is my custom, after making a complete correction of any existing error of refraction, to resort to four muscle tests, and when these do not clear my mind of doubt, I try a fifth test. [I have since learned from study and the observation of cases that all tests for lateral heterophoria are unreliable while the eyes are under the influence of a mydriatic.] These will be explained in the order in which I take them. The first is the Maddox rod test. Providing the lenses correcting the errors of focus are alike, the rod three-fourths of an inch long, set in an opening of corresponding length through the center of the metal disk, is all that could be desired for this test. It can be readily seen that, if before one eye is a +1.00 and before the other a +2.00, a serious error could result in the test for vertical heterophoria. The optical center of the lens is immediately behind the center of the three-quarter inch rod. For three-eighths of an inch above and below the optical center of the lens the streak of light can be seen, so that, in the case supposed above, there must be a partial or complete correction of an existing hyperphoria, or there must appear an artificial hyperphoria as a result of the difference in prismatic effect of the lenses, provided the axes of vision pass above or below the centers of the two lenses. To counteract this chance for error to creep in and to result in bad practice, I conceived the idea of covering all the rod by pasting paper over it, except one-eighth inch of its center. If the streak is seen through this small opening, it must be seen through (or very near) the optical center of the lens before that eye; and at the same time the blaze of the candle must be seen through the optical center of the lens before the fellow-eye. The chance for error thus eliminated by modification of the Maddox rod (Figure A), this test may be resorted to with a considerable degree of confidence. With the lens or combination of lenses needed for focal correction, placed in the posterior receptacle of the frames, the metal disk containing the rod is placed in the anterior. The lighted candle or gas jet is twenty feet from the patient. The eye whose muscles are to be tested is always the one before which the rod is placed. Let it be the right eye first. The disk

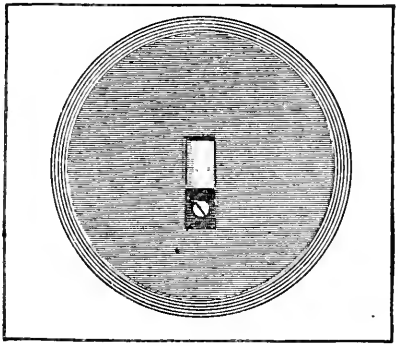

Figure A.

is placed vertically. The patient is asked to look at the candle, which he sees distinctly with his left eye; and at the same time he sees a streak of light running horizontally. The left eye is the one that is fixed. If there is vertical orthophoria, the streak will occupy Position 2 in Figure B; if there is right hyperphoria, the streak will occupy Position 3 in Figure B; or if there is right cataphoria, the streak will occupy Position 1 in Figure B. The amount of vertical heterophoria is measured by that prism which will throw the streak, when occupying Positions 1 or 3, into Position 2. When right hyperphoria is found, the left eye, when tested in the same way, will show the same degree of cataphoria. The condition of the superior and inferior recti having been thus determined, the disk must be revolved until the rod comes to the horizontal, when the streak will become vertical. The right eye being first under test again, if there is horizontal orthophoria, the streak will be found in Position 5, Figure C; if there is esophoria, the streak will go to the right as shown by Position 6, Figure C; or if there is exophoria, the streak will go to the left, as is shown by Position 4, Figure C. If there is right

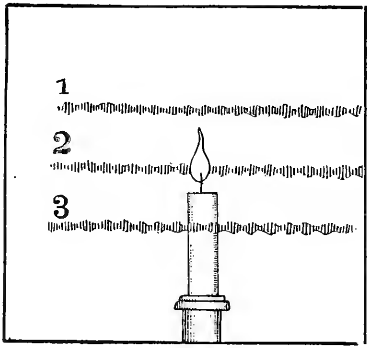

Figure B.

esophoria, the left eye tested in the same manner will show esophoria, and exophoria where there was right exophoria. The degree of horizontal heterophoria is determined by that prism which will remove the streak from Positions 4 or 6 to Position 5, in Figure C. The rod test resorted to in the way described is trustworthy, in that it does not show a condition that has no existence. By it we may not be able to judge of the necessity for an operation, if we are to be guided by the line which I will draw later between operative and non-operative cases. If in any case we find 3° or more of hyperphoria, or 10° or more of esophoria or exophoria, we can safely conclude that the patient will be a subject for operation either immediately or remotely.

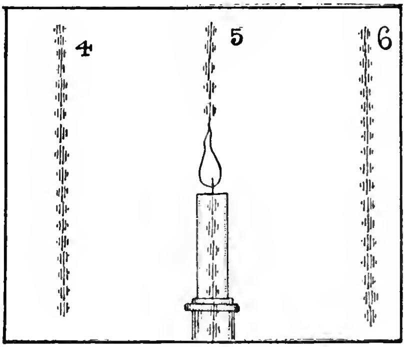

Figure C.

In further investigation of the case, the rod is laid aside and the second means of testing is taken up. The Maddox double prism, or better, my modification* of the same, is used. This is placed in the anterior division of the test

* This consists of two separate prisms 6° each, bases toward each other, and put in rim of same size as those containing lenses in test case, the line of the bases passing exactly through the center of the rim.

frames, as was the rod, and is so set as to double the candles seen by that eye, and make the one in the same vertical plane with the other. While this is being done the fellow-eye may be covered by an opaque disk. After the double images have been made and properly placed, the fellow-eye is uncovered, when at once a third candle comes into view. If there is orthophoria, the third image will be in the same vertical plane with the other two, and just halfway between them. While in this method either eye may be considered as the one under test, it is my custom to take the one in which there is the single image. The double prism being before the right eye, the left is then the one to be tested. The middle image going to the left, there is left esophoria; going to the right, there is left exophoria; going nearer the lower blaze, there is left hyperphoria; going nearer to the upper blaze, there is left cataphoria. In the same manner the right eye may be tested. The degree of heterophoria is determined by the prism that places the middle image in line with the other two, and equidistant from them. The double prism test readily shows any compound muscular error that may exist. To illustrate: There may be left esophoria and left hyperphoria, and when this is the case the middle blaze will not only go to the left of the vertical plane of the other two, but it will also approach the horizontal plane of the lower light. The rod cannot, at the same moment, show the two conditions. Of the two tests, I consider the rod the more reliable, though often they both are attended by like results.

In continuing the double prism test, a card on which there is drawn or printed a single horizontal line with a dot in its center, is held before the patient at a distance of sixteen inches. After placing an opaque disk before one eye—say the left one—while the double prism is allowed to remain before the other, the card is elevated or depressed until

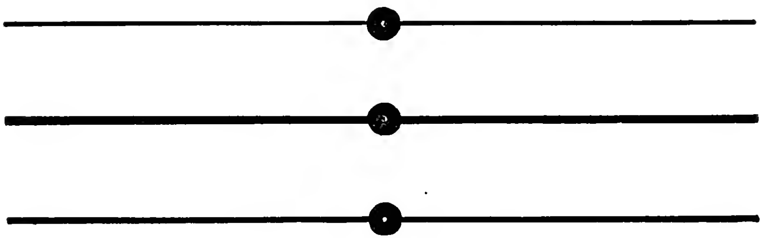

Figure D.

the patient sees two lines with equal distinctness, and the dots in the same vertical plane. On removing the disk from before the other eye a third line appears between the other two. If there is orthophoria, the middle line will be equally distant from the other two, and the three dots will be in the same vertical plane, as is shown in Figure D. If there is esophoria, the middle dot will be found to the left of the vertical plane of the other two, as shown by Figure E; if exophoria, it will go to the right of this plane, as is shown by Figure F. When a vertical error exists it is shown by the middle line going toward the lower in hyperphoria, as in Figure G; or toward the upper in cataphoria, as in Figure H. As in the distant test, so in the near, the existence of a

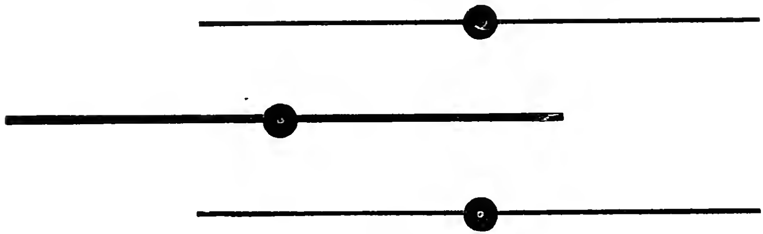

Figure E.

compound error is shown at the one glance, by the middle line going to the right or left and approaching the top or bottom line.

In this near test with the double prism, the same vertical

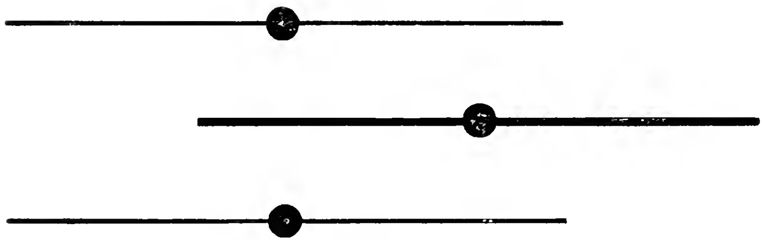

Figure F.

heterophoria is shown as was manifested in the far test; but the degree of error manifested is usually a little more in the near than in the far test. If there is esophoria in the far test, there is either a less degree of esophoria, or, as is often the case, there is exophoria in the near. In only very few cases is esophoria greater in the near than in the far. More exophoria is nearly always shown by the near test than was brought out by the far test. Orthophoria for distance and exophoria in the near is common.

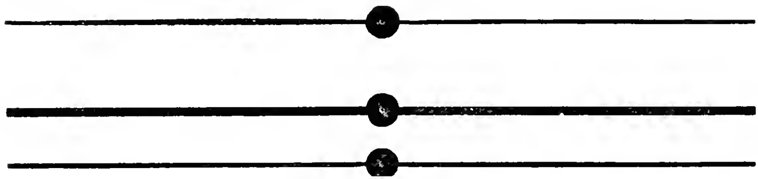

Figure G.

In both the near and the far test with the double prism, the patient may see but two images, the vertical error being so great that the middle has blended with either the upper

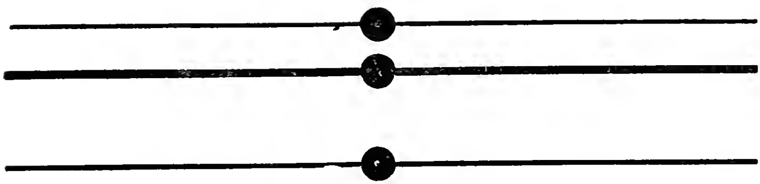

Figure H.

or the lower image. The result is easily reached by holding the opaque disk before first one eye and then the other. With the disk before the eye with the single image, if the two lights or two lines are still seen, it proves that the middle image was blended with one of the other two. By placing the disk now before the other eye—the one with the double image in it—the top line only is made to disappear, showing hyperphoria to exist in the fellow-eye; or if the bottom line is the one to disappear, the condition is shown to be cataphoria.

The third in order is the *strength* test. I rarely apply this except to the superior and inferior recti; though I am more and more convinced that it also has a real value when applied to the external recti as well. For testing the strength of the superior and inferior recti; a Maddox double prism (4° each) is most convenient. Either eye can be taken first. The patient is made to look first through the upper prism at the candle twenty feet distant, and it is noted whether two lights or one are seen; and if two, their distance apart. Now the double prism is elevated so that the eye before which it is held looks through the lower prism; and the same note is made as when the prism was in the former position. If the two images are the same distance apart in the two positions of the prism, it shows equal strength on the part of these opposing muscles; but if, when the upper part of the prism is used, the two images are near each other, say one or two inches apart, while they are six or more inches apart when the lower part of the prism is used, there is an excess of power in the superior rectus. The same test applied to the fellow-eye would show an excess of power in the inferior rectus. This test is confirmatory of the two preceding tests, and much reliance can be placed in it.

As to the strength test of the external rectus, the following is a good rule: If that muscle can overcome a prism of more than 8°, there is exophoria; if less than 8°, esophoria is to be suspected.

The fourth test is that by means of the plane deep red glass, nothing else being before the eyes except the lenses correcting focal errors. While in a large proportion of cases this test is negative, yet it is one most useful, as will be presently shown. The image of the flame (twenty feet distant) on the retina of the eye before which the red glass is placed, is, of course, greatly modified as compared with the image in the fellow-eye. If there is orthophoria, or if there is heterophoria of low or even of moderate degree, the images will be fused and only one blaze will be seen; but if there is heterophoria of high grade, the images may not fuse, a red light being seen by one eye and a white light by the other. The patient is asked to fix the white blaze, and at the same time observe the position of the red blaze, and the distance between the two. Figure I illustrates the result brought about by this test. The bold, sharply defined candle (7) represents the white one, the pale candles above (8) and to the right (9) of the other represent the red candles. The red glass being first before the right eye, the patient at once says he sees two candles, the red one being directly above the white, and that they are from one to four or more inches apart. This is positive evidence of right cataphoria, or, if the term is objected to, left hyperphoria. The extent of the deviation is measured by that prism which will cause the images to fuse. If there is vertical orthophoria, while at the same time there is horizontal heterophoria of high degree, the red light (9) will appear in the same horizontal plane with the white one and they will be from one to many inches apart (in one of my cases they were thirty inches apart). If there is right esophoria, the red candle will be to the right, as in Figure I; if right exophoria, then the red candle would be to the left of the white one.

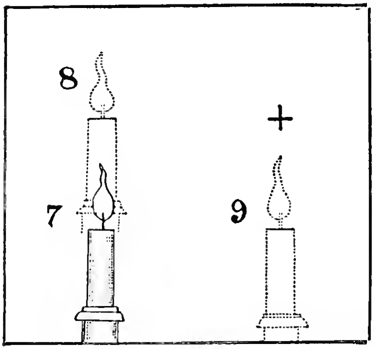

Figure I.

If a compound muscular error exists, the red glass in suitable cases will show it at a glance. The head being perfectly erect, if there is right cataphoria and esophoria (the red glass before the right eye), the red light will be above and to the right of the white, occupying the position + in Figure I. In all of the cases of this class there is, without the interposition of the red glass, binocular single vision, as can be most readily determined. Otherwise the test would be without value.

The fifth test is never resorted to when the fourth (the red glass test) results in diplopia. In some cases, under the first three tests, the results are conflicting, especially as to the vertical heterophoria. To clear the doubt, if possible, a Maddox double prism (4° each), line of bases horizontal, is placed before one eye, while another double prism (6° each), line of bases vertical, is placed before the other eye. On looking in the direction of the candle twenty feet distant, four candles are seen, two in a vertical plane and two in a horizontal plane. If there is orthophoria, these planes will bisect each other, and the four candles will form a perfect diamond. If there is hyperphoria, the horizontal plane will cut the vertical plane nearer the lower candle, sometimes passing through it. If there is a horizontal as well as a vertical heterophoria, the right image may run into the lower one, the left one going farther away from, but stopping in the same horizontal plane with, the latter. Two having gone into one, but three images remain, and these form a right-angle triangle.

It must be confessed that, in some cases, after all known tests have been resorted to, there still remains doubt as to what the true muscular condition is. In such cases it is best to do nothing.

In this paper I have not referred to the Stevens phorometer, one of the best if not the very best, means of determining heterophoric conditions. The chief objection to it is its cost.

Having thus far discussed heterophoria and some of the tests that may be resorted to for its determination, I am ready to draw *a safe line between operative and non-operative cases*. On the *operative* side of the line must be placed all cases in which the plane red glass produces diplopia. On the *non-operative* side of the line should be placed, at least for a time, all cases of heterophoria in which there is not diplopia when the plane red glass is before one eye. Prisms, or decentered lenses, in position of rest should always be resorted to primarily in all cases falling on the non-operative side of the line. [I now believe this teaching to be erroneous. Prisms and decentered lenses in position of rest make the strong muscles stronger and the weak muscles weaker, developing a so-called latent heterophoria, which should never be done. But this more fully at end of this chapter.] In those cases in which the third theory for heterophoria, given in this paper, is the true one, nothing but prisms placed as above will ever be needed. [I still believe this to be true, but these cases are rare.]

In operating on cases responding to the red glass test, a fairly free division of the tendon of the strong muscle must be made. One or more fibers should be left above and below in order to prevent too great an effect, immediate or remote. The guide as to when enough is done short of a complete division of the tendon is a fusion of the red and white lights. While operating, the test should be resorted to, to show what effect has been gained by the cutting already done. In no case should the red light be made to cross to the opposite side of the white light, as will nearly always be the case when the whole tendon has been severed. If a complete tenotomy is done accidentally or on purpose, an advancing stitch is nearly always necessary.

In cases demanding an operation when there is no response to the red glass test, the division of the tendon must be done with still greater care, else an over-effect will result.

In addition to the modifications inclosed in brackets in the foregoing paper, I have omitted a few paragraphs descriptive of the plan I then followed of using prisms in position of rest, for the relief of symptoms dependent on low degrees of muscular errors. While in some cases this treatment was satisfactory, in the majority of these cases the relief was only temporary; and in other cases the prisms were a source of increased annoyance from the beginning. I now believe prisms in position of rest indicated only in cases of decentration of the maculæ. Even in these cases the chief reason for using prisms is that they give to such eyes the ability to obey the law of projection. In all other cases the development of the weak muscles by graduated rhythmic exercise is the proper thing to be done, when the muscle error is not too great.

While in this chapter the line drawn between operative and non-operative cases is a safe one, it is not sufficient. Those just beginning to operate would do well to practice on the safe line. While there are many cases that, under ordinary circumstances, have binocular single vision, in whom the red glass will develop diplopia, there are many more cases of heterophoria sufficiently great to demand operative interference, in whom the red glass is incapable of bringing about diplopia. All exophoria for distance should be relieved by operations; all intrinsic esophoria in the near should be corrected by operations; hyperphoria and cataphoria of 2° or more should be operated upon. Under the exclusion test, should the eyes reset in both the distant and near tests, there is certainly enough muscle error not only to justify but even demand an operation. Exophoria in the near with orthophoria for distance should never be operated upon; and, *a priori*, exophoria in the near with esophoria in the distance should not be operated upon. In the former case an operation giving relief to a part of the exophoria in the near would give an esophoria for distance; in the latter case, the operation for the exophoria would give an increase of the esophoria. The proper method of dealing with cases like these is fully set forth in the chapter on "Rhythmic Exercise."

Is there such a condition as latent heterophoria? If so, is it good practice to bring it out by prisms in position of rest? When there is a want of harmony between the external and internal recti, or superior and inferior recti, one or more of the several tests will show it; and having found the error, the line of duty is to combat the known enemy and not add to its power by uncovering the so-called latent force. The practice of making manifest a latent muscle error has been confined almost entirely to the superior and inferior recti. For illustration: On the first examination the patient shows left hyperphoria, ½°; the second and third examinations show the same thing; and so on for any number of examinations. Imbued with the idea that there is such a condition as a latent hyperphoria, the patient is given a prism of ½°, base down, for left eye, with instruction to wear same continuously for a few days. In due time the patient returns. The prism is removed and the test is applied, with the gratifying (?) result that now there is hyperphoria ¾°. The ½° prism is allowed to remain before the left eye and a prism of ¼°, base up, is given for the right eye; and the patient is directed to wear these all the time, and return to the office in a week or two. Now, with prisms removed, 1° of left hyperphoria is shown—½° of latent has been added to the ½° manifest. Increasing the strength of the prisms further, there is brought into the manifest state still more of the latent hyperphoria; so that a patient who had primarily only ½° of hyperphoria, has now 1½° or 2°, possibly more, of this error. The point must be finally reached, however, beyond which it is not possible to uncover an additional quantity of the so-called latent trouble. This limitation is due to one of two causes, viz., (1) the prisms become so strong that their continuous use brings too much fatigue to the stronger muscle, which would have a greater tendency to weaken than to still further strengthen; (2) the actual turning of the eye, resulting from the use of the prism, finally reaches a point backward (toward the apex of the object) that is equivalent to setting the insertion of the stronger muscle back, while the weaker muscle finds its relation to the rotated globe equal to a slight advancement. The smaller the difference in the relative strength of the two muscles, the sooner would this point be reached. To illustrate: If two men, the one being stronger than the other, are to lift a certain weight by means of a stick beneath it, it is plain that if the load be placed in the middle of the stick the weak man will have to lift too much for his comparative strength; but if the load be placed nearer the stronger man, the weaker man can now lift with him and not be strained more than he. The changed position of the globe is to the weaker muscle what passing more than half the stick is to the weaker man. I may be allowed here to say parenthetically that there is another way to enable the weaker man to lift with the stronger: develop his (the weaker man's) muscular power by gymnastic exercise.

It is fortunate that, in making manifest a latent muscular error, the practice has been to compel the patient to wear the prisms continuously, thus setting a limit to this work. If such a thing were attempted by the proper gymnastic exercise of the strong muscle, every week more and more of a supposed latent error would be brought out; because day after day the strong muscle would be made stronger by the exercise. In this way it would be possible, in time, to augment a slight degree of hyperphoria, until finally it would be converted into a hypertropia. The same thing would hold true as to any of the extrinsic ocular muscles.

I believe that we should be content with whatever muscle errors we find manifest; the smaller the degree of a manifest error the happier we should be. In no case should we institute a search for a hidden error, be the manifest error great or small. If the error is great, an operation on the strong muscle is at once indicated; if the error is small, we should strive to make it less, day after day, by directing our prismatic power toward the weak muscle in such a way as to develop its strength. To accomplish this by means of rhythmic exercise, resorting to it intermittingly, will be easy.

I will close this chapter by giving the technique of what I conceive to be the proper method of operating for the cure of heterophoria. In no case of any of the several forms of heterophoria should a complete tenotomy be done; in no case should a second operation be done on any one muscle.

When the error to be relieved is at all great, the operative effect should be divided between the two corresponding muscles; but the aim should always be to fall short of a full correction rather than incur the risk of an over-effect, leaving a small part of the old error to be corrected by rhythmic exercise. After the first operation the second one should be delayed at least one month; and another month should elapse before resorting to exercise for the relief of any remaining error. Knowing that a very small division of the center of the tendon will effect but little, if any, change in the muscular error, the operation should be undertaken with the understanding that it must be made more or less extensive; the greater the error the more nearly must the division approach the margins of the tendon. The effect of a partial tenotomy depends not solely on the extent of the division of the tendon, but also on the amount of retraction of the divided portion. The retraction can be very little if the cutting of the capsule of Tenon is not coextensive with the cutting of the tendon.

The Operation of Partial Tenotomy,

as done by myself, is performed under cocaine anæsthesia, with the following instruments: Stop speculum, ordinary fixation forceps, and Stevens's scissors and hook. If the condition is hyperphoria, I operate first on the superior rectus of the hyperphoric eye. Asking the patient to look toward the feet, I seize with the fixation forceps the conjunctiva, capsule, and tendon, at the point of insertion of the latter. Between the forceps and sclera I make a small cut with the scissors through all the structures held by the forceps, making as small a cut as possible, which is usually one-tenth to one-eighth of an inch. Laying the scissors down, but still holding on with the forceps, I take the hook, and, passing it through the opening, which I intended should be in the center of the tendon, test the strength and extent of the undivided fibers in both directions. If convinced that there are many uncut fibers on both sides of the opening, I lay down the hook and take up the scissors again. Without enlarging the conjunctival opening, I pass the closed scissors in, but immediately open them, passing one blade behind the tendon and the other in front of the capsule. Having made as many snips as I deem safe in that direction, I withdraw the scissors and test with the hook. Having decided that I have gone as far in that direction as is safe, without the hook as a guide, I again take the scissors, while still holding on with the forceps, and divide the capsule and tendon in the same careful manner, in the other direction. I now lay the forceps down, and, with hook in hand, test the strength and extent of undivided fibers in each direction. If more is needed, it is done under the guidance of the hook. With every snip of the scissors both capsule and tendon are divided, and after each snip the hook is made to tell if more must be done. The habit of resorting to one or more of the muscle tests as the operation proceeds is unnecessary, and may be misleading. In a case where there is diplopia with the red glass, I would fuse, or nearly fuse, the two images, if this could be done short of a complete division of the tendon. To know that this has been accomplished, the red glass test must be resorted to. When the fusion is made to take place there is enough of the condition left to demand a subsequent operation on the corresponding muscle. Necessarily some bleeding attends these operations. So as to give a clear field for operating, the blood must be removed by means of pledgets of previously prepared absorbent cotton. In the use of these pledgets care must be exercised that the cornea be not touched, since the slightest touch might remove its epithelium, which has been so acted on by the cocaine as to make this accident easy. If the patient should suffer after a partial tenotomy, it is usually due to accidental corneal abrasion. The after-treatment I usually prescribe consists of morphia sulph., gr. i.; acid boracic, gr. x.; aqua distil., f℥i. Two drops in eye, three or four times a day. No bandage or protection of any kind need be applied. While the patient should not be kept in his room, he certainly should not be allowed to use his eyes in continuous near work for at least a few days.

At intervals of a few days, when convenient to the patient, the tests should be applied and results should be noted. If, at the end of four weeks, there should be enough hyperphoria remaining to indicate a second operation, a partial tenotomy of the inferior rectus of the other eye should be made, in the same careful manner as was the operation on the tendon of the superior rectus at the first operation. The one muscle is as easily operated on as the other. The hyperphoria must be great that cannot be almost completely cured by these two operations. Great care must be exercised in the second operation, lest an over-effect may follow.

Varying the position of the eye, the technique of the operation on the internal recti in a case of esophoria, and on the external recti in exophoria, is exactly the same as that already given for the superior and inferior recti in a case of hyperphoria. Between operations I allow my patients to return home, unless they reside at too great a distance.

Not infrequently an esophoria or an exophoria is so great in degree that a partial tenotomy of the two corresponding muscles, although the tendons may be almost completely divided, does not reduce the error within the range of possibility of completing the cure by gymnastic exercise of the weaker muscles. In such cases I shorten one or both of the weaker muscles, after the method set forth in Part III. of this book. Since this operation must necessarily be attended by pain and inconvenience, I prefer doing what remains to be done on one muscle. If it was no more annoyance to a patient than a partial tenotomy, I would prefer dividing the effect sought by shortening, between the two muscles.

Whether one or several of these operations is to be done, I always aim to fall short of a full correction, rather than incur the risk of an over-effect. We may never expect to have means of guaging to a nicety the effect of these operations. It is well, therefore, that we can call to our aid, in completing a cure of muscle errors, such a simple and so entirely harmless a method as rhythmic gymnastic exercise of weak muscles.

CHAPTER II.

THE NECESSITY FOR COMPLETE SUSPENSION OF ACCOMMODATION BY MYDRIATICS IN THE ADJUSTMENT OF GLASSES.

IF the accommodation could be suspended instantaneously, and then, after the work of refraction has been accomplished, could be as speedily restored to the normal, who and where is the oculist who would not exercise such magical power in *all* his cases of refraction? If the exercise of this supposed magical power would be justifiable, then there must be some strong reasons for using the means really at our command for putting at rest the ciliary muscle when a focal error, whatever may be its nature, is to be corrected. It is the object of this paper to give the reasons that not only justify, but actually demand, the use of the mydriatic in refractive work.

For the sake of fairness, the reasons against the use of the mydriatic, except in rare and remote instances, will be given:

1. It interferes with the business of the patient. This of course applies to the banker and the butcher, to the lady whose business is to read the latest novel, and to the girl

who has to sew for her daily living—in fact, about all of our patients need the eyes for near use at least a part of every day.

2. The general inconvenience to the patient, leaving out the question of using the eyes in near work. The pupil being dilated, a flood of light enters the eye and the patient is annoyed by the dazzling it produces; and, except in myopia, there is always an attendant dimness of both distant and near vision, greater or less in degree. In rare instances there is a slight toxic effect.

3. The chromatic and spherical aberration resulting from the dilation of the pupils is not only annoying to the patient, but is otherwise undesirable.

4. The operator is delayed, and his time is, of course, valuable.

5. There is the alleged danger that, in old people, the mydriatic may excite the glaucomatous state.

6. Glasses prescribed without a mydriatic are often comfortable.

7. One other reason which has been advocated, but which is absurd on its face, is that the error, especially if it be astigmatism, cannot be as thoroughly corrected when the eye is under the influence of a mydriatic as when not.

In presenting the numerous reasons for the use of the mydriatic in the work of refraction, all the reasons above given against its use will be met.

While in some cases glasses may be prescribed simply to sharpen vision, it must be confessed that the greater number of cases coming under the observation of the oculist are persons who suffer because of strain. This leads us to inquire: What is eye strain? A clear understanding of what the answer to this question should be will go far toward settling the question of the proper line of practice intended for its relief. None will controvert the statement that

Eye Strain Is Muscle Strain;

and that the muscles concerned in the visual act are: First, those regulating the quantity of light admitted into the eye and the direction of its rays (these are the two sets of fibers in the iris and the ciliary muscle); secondly, the extrinsic muscles—the recti and the obliqui—which are concerned in directing the visual axes and in keeping the naturally vertical meridians of the corneæ so related that images may fall on corresponding parts of the two retinæ. Muscular *action* is not muscle *strain*, unless the action is either too prolonged or too great for the inherent power of the muscle. Some, by their teaching, would show that only the ciliary muscle is susceptible of strain; and that ciliary strain alone is capable of bringing into existence that long train of nervous phenomena with which the oculist and, of late years, the neurologist are so well acquainted. There are others who are accused of believing and teaching that the extrinsic muscles are alone susceptible of that fatigue which brings discomfort, in varied forms, to our patients. There are not a few, however, whose practice is governed by the sounder doctrine that both the intrinsic and extrinsic eye muscles may be put to the necessity of doing more work than their strength will bear; and that the consequent strain, whether in the one set or in the other, or in both at the same time, will develop headache, vertigo, confusion of thought, and a host of other phenomena. While glasses, prescribed for the correction of focal errors, were once thought capable of curing all symptoms depending on eye strain, the time is now when no such claim can be sustained. Lenses that give a perfect correction of existing focal errors may in some instances augment, rather than allay, the suffering due to eye strain. Such patients would be better without lenses until the chief cause of suffering, in the individual case, has been found and, by the proper treatment, cured.

But I am not the one to cry out against the prescribing of glasses. My wearing lenses is sufficient evidence of my regard for, and my appreciation of, them. Properly determined, scientifically prescribed, and correctly worn, they do only good. But in prescribing glasses we must take into consideration both the focal error and the muscular adjustment, particularly the adjustment of the internal and external recti. Since glasses can do more than relieve ciliary strain—they can, if properly selected, relieve strain of the internal and external recti, independent of prismatic effect;* also strain of the oblique muscles in cases of oblique astigmatism—they should be scientifically prescribed, after a most painstaking study of the focal error and the muscular adjustment.

For the present, fixing our attention on focal errors, we find that there are these: myopia, hypermetropia, and the several kinds of astigmatism. In emmetropic eyes there is no strain, in the proper sense, when used in moderation.

In simple myopia of 3 D. or more, the ciliary muscle is never called into action, and therefore can never be strained. If such eyes give annoyance, other than dimness of distant vision, the cause must be sought, and will be found, in the relationship of the extrinsic muscles.

In simple hypermetropia the ciliary muscle, during waking hours, is ever acting until quieted by age. Any action of the ciliary muscle for sharpening distant vision is strain: and in such eyes overaction (strain) is necessary in order to good near vision. In some of these cases the ciliary muscle is hyperdeveloped; the center controlling it has an abundant supply of nerve force; and there are no symptoms resulting from the strain. Other hypermetropes are not so fortunately constituted; and the ciliary strain caused by the refractive error is felt in some form or other.

In astigmatism, of whatever kind, with the principal me-

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*See *Ophthalmic Record*, Vol. II., No. 11.

ridians in the vertical and horizontal, or, if oblique, the obliquity being in the same direction and at the same angle in the two eyes, the astigmatic refraction also being equal in the two eyes, there is ciliary strain directed against this refractive error. As to the character of the effort made by the ciliary muscle there is some difference of opinion. Whatever may be the nature of this strain, it is capable of correcting wholly only the lower degrees of astigmatism, and only a small part of the higher degrees of this error; but that the effort is being continually made, for distant and near vision, in cases of hypermetropic and mixed astigmatism, also in myopic astigmatism, when near vision is attempted, there can be no doubt. This effort is *strain* if the action is equal and simultaneous in all parts, holding the focal interval on the retina, or adjusting the rays of first one principal meridian and then those of the other, as vertical or horizontal lines may be viewed; it is *strain* if the ciliary muscle acts, as described by Martin, in sections, the one opposite the other, thus, by altering curvature, developing a lenticular astigmatism correcting in whole or in part the corneal; it is also *strain* if the longitudinal fibers of Bowman are alone concerned in the effort of correcting the astigmatism, by tilting the lens on an axis in a plane with the corneal meridian of greatest refraction, thus producing a lenticular astigmatism counteracting to some extent the corneal. In oblique astigmatism, as usually encountered, there is a demonstrable necessity for action (strain) on the part of the obliques,* which in these cases is a factor added to the ciliary strain excited by the astigmatism. The strain caused by astigmatism is nearly always a source of annoyance to the patient, and should, in all cases, be fully corrected, regardless of any and all other conditions.

Ciliary strain is an effort on the part of the ciliary muscle to increase the refractive power of the lens, as in hypermetropia, or to render it astigmatic by tilting or otherwise, for the correction of a corneal astigmatism. This action, or these actions, of the ciliary muscle is, from necessity, brought into existence in very early life, and because of daily repetition becomes a fixed habit of the muscle—a habit whose existence continues, in nearly all cases, for a time after the cause for it has been taken away by properly adjusted lenses. If this is true, who knows that his work has been correctly done when he undertakes the correction of a refractive error, while the ciliary muscle is allowed to continue at its old work? That glasses thus fitted often (for a time) give satisfaction is but a verification of the old adage that "guess work is as good as any when it hits."

How often do we find ourselves declaring, what is a truth, that ophthalmology is more nearly a pure science than any other department of medicine? And is not this true mainly because of our perfect knowledge of the refraction of the

* See *Ophthalmic Record*, Vol. I., No. 1.

eye and the conditions that result from errors of refraction? If there were no modifying conditions, nothing could be more scientific than the full correction of errors of refraction, which could not be done accurately without first putting at rest the self-correcting power, the ciliary muscle. Since these modifying conditions are known and can be removed, it is the plain duty of every oculist to determine, by a most thorough and painstaking examination, under the only favorable condition, suspension of accommodation, what the refractive errors are, even though because of the existence of some known muscle error, he might know that it would not be proper to give fully correcting lenses at that time; for, having cured the muscle error, his record would enable him later to give the full focal correction. There is no condition of the extrinsic muscles which would be disturbed by a full correction of any astigmatic error; there is no astigmatic error which may not be partially concealed by ciliary strain.

In the work of refraction how fortunate for science and practice, for patient and practitioner, that we have at our command

MYDRIATICS,

whose effect is to temporarily suspend the self-adjusting power of the faulty eye, during which period artificial correcting means may be accurately determined!

While a mydriatic does not in the least interfere with any of our objective methods of examination, it gives greater accuracy to most of these. All must confess that the

Ophthalmoscope

can measure more correctly the refractive error of an eye, when under the influence of a mydriatic, than when it is not. The man most skilled in estimating the refraction of eyes by means of the ophthalmoscope must confess that it took both time and practice to enable him to voluntarily suspend his accommodation, with his eye on the dark side of the instrument; then how can he expect the patient, whose eye is on the light side of the instrument, to learn in a minute to suspend an *involuntary* power—one that is being stimulated into activity by the light that is thrown on the retina? When there is forced suspension of accommodation (by a mydriatic) in the patient's eye, and acquired suspension of accommodation (by practice) in the observer's eye, then there can be some degree of accuracy in the measurements of the ophthalmoscope; otherwise there cannot be.

The valuable objective examination of

Skiascopy

could not be so well made, nor could the results be so accurate, if done when the eye is uninfluenced by a mydriatic. Properly practiced, under favorable conditions, skiascopy, in addition to detecting and measuring myopia and hypermetropia, shows quickly the existence of astigmatism, the kind and quantity, and, approximately, the location of the principal meridians. A method capable of doing so much should not be interfered with by an active ciliary muscle and a contracted pupil.

When we come to the method of

Ophthalmometry

we find that an active accommodation neither hinders nor helps. Since the ophthalmometer deals only with the cornea, we know that its findings must be the same both with and without a mydriatic, for a mydriatic can effect no change in either the corneal curvature or the corneal reflection. If no effort on the inside of the eye were ever made for the correction of corneal refractive errors, as is true in the aphakial eye, and all errors of refraction existed in the cornea alone, we would then have in the ophthalmometer an instrument infallible in its findings, and the mydriatic could be sent into "innocuous desuetude." Although ciliary action prevents our relying implicitly on the ophthalmometer, it is nevertheless a great aid in refractive work. Those who bought this instrument and then consigned it to the attic, if they will only bring it down again and cultivate its acquaintance a little more closely, will find in it a worthy friend. Those whose enthusiasm has led them to trust this instrument implicitly will, on more careful study, find themselves victims of misplaced confidence, for the reason already given in this paper. The great sin for which the ophthalmometer will have to account is that its introduction led to a vigorous renewal of the effort to discard the mydriatic in the work of refraction.

If the mydriatic is an aid in objective examinations, and ought not to be dispensed with, it is still more essential when the subjective methods are to be resorted to, as they must be if we aim at accuracy in our work.

In our subjective tests there are causes for error other than activity of the accommodative muscle, but unfortunately none of them are so easily removed as the latter. For the stupidity of the patient under examination there is no perfect remedy; for the carelessness and haste of the operator there is a cure in the combination of knowledge of the conditions under study and a determination to do the best possible under the circumstances.

When we resort to the use of the

Lenses of the Test Case

our aim is to prove the "findings" of our objective tests. If the fixed habit of strain is not suspended by a mydriatic, though we labor long and earnestly, we can never be certain that what we have done is absolutely correct. No one has ever yet learned the art of coaxing the ciliary muscle into a state of rest. When capable of acting, it is always trying to correct the error which your lenses are searching out. This subjective test, when unopposed by ciliary power, is soon satisfactorily ended.

If the need of a sphero-cylinder has been determined, and yet there is a "modicum of doubt" as to whether the spherical part should be diminished and the cylindrical increased in strength, or *vice versa*, the confirmatory agency is the

JACKSON SPHERO-CYLINDER,

the use of which can be depended on only when there is suspension of the accommodation.

If a perfect knowledge of the full error of refraction in every case is necessary, and this knowledge can be attained only by the suspension of the accommodation, then the reasons against the use of the mydriatic can be easily disposed of.

As to the interference with the business of the patient, superinduced by the mydriatic: He comes to the oculist because of the fact that his eye-strain interferes with his business in one way or another. Relief is what he needs and what he should have—relief in the fullest sense of the word—not present relief only, but relief for the future as well. When told that his trouble is due to eye-strain, he naturally infers that if the cause of that strain is removed freedom from trouble would follow. He comes, possibly, from a great distance, and, though his business may need him at home, he is off seeking comfort, worth more to him than gold. He is a willing subject, and complains at nothing that is needful to be done. He is a young man—old men may suffer with eye symptoms brought on by strain of the extrinsic muscles, but not from ciliary strain—and his accommodation is active. This must be suspended if the full error is to be known. If he is left to choose, after a fair statement of his case has been made, he will agree to the loss of time that must follow the use of the mydriatic, for he wants the work done correctly. Methods and means that are correct for patients at a distance are correct for home people. As to the amount of interference with business, the difference is decidedly in the favor of the home man. Besides, the business man, being a sensible man, will not complain at loss of time necessary in order that relief may come, for he remembers how his troubles have, at times, incapacitated him for effective work. There are few men whose work in bank, store, or elsewhere, cannot be done, for a reasonable time, by a substitute. What is true of the man of business is true of all patients, lawyers, doctors, school teachers, artists, sewing girls, etc. But the necessary loss of time from the proper use of a reliable mydriatic need not exceed twenty-four to forty-eight hours. If it were necessary, the patient might be sent at once from the doctor's office to the counting room, or wherever his duties might call him.

Of course near seeing so quickly done would have to be effected by means of a temporary pair of lenses.

The mydriatic whose power is effective and yet, as compared with atropine, evanescent, is the one that should be chosen. There are few ciliary muscles that will not respond to a solution of hydrobromate of homatropine of the strength of one-third grain to twenty drops of water, ten drops of which, drop by drop every five minutes, should be put in each eye. In ten minutes after the last instillation the study of the refraction can be confidently commenced. The work completed by both subjective and objective tests, within an hour and a half all told, a few drops of a 1-500 solution of eserine may be used, the same to be repeated the next morning early. The patient may then be sent about his business. By the next morning the effect of the mydriatic is entirely gone.

As to the general inconvenience to the patient: This can be readily borne, or modified by smoked glasses, etc. Systemic effects are rare, and can be combated by appropriate remedies—brandy and morphia.

As to loss of time to the operator: This is a myth. While the muscle test and the correction of the refractive errors must be done by the operator, he can safely commit the use of the mydriatic to the office girl, whose time is not so valuable as his own. This method, too, is restful both to the doctor and the patient; for the muscle tests should always be made when the eyes are uninfluenced by a mydriatic. After the eyes are brought under the influence of the mydriatic, the subjective and objective examinations of the focal errors are soon over, and the patient does not have to be reëxamined on the next day, nor at any other time, as a rule.

As to the objection that the mydriatic may increase the tension to the point of exciting an attack of glaucoma: This objection can weigh but little when we consider that this exists only in persons beyond middle life; and that in these patients the ciliary muscle has lost more or less of its power, and a weak mydriatic serves to completely suspend what remains. In these cases, especially if the patients are beyond fifty-five years, the prime object is not to act on the ciliary muscle, but to dilate the pupil, in order that a thorough examination of the fundus may be made for the detection of central choroiditis, so common in old people; also that the periphery of the lens may be examined for beginning opacities. When these conditions are detected early, as is well known, proper therapeutic means may check their progress, and make it possible for the patient to have comfortable vision during the remainder of life. Through the small pupil of the old, these changes could not be readily detected. After the proper glasses have been determined, and the fundus and lens have been thoroughly investigated, the myotic should never be omitted if the patient is beyond middle life.

While advocating the complete suspension of the accommodation, that full knowledge of the refractive errors may be attained, and made a matter of record, I would not be understood as advocating that the myopic and the hypermetropic refraction should always be fully corrected in every patient, at the beginning. On the contrary, in the light of our present knowledge, such practice should be avoided, not only for the comfort of the patient, but also for the credit of the practitioner. In the present state of our knowledge, there is not a single reason for not correcting fully all the astigmatism that may be found in any case; but not so with the hypermetropia and myopia that may complicate it. The relationship between the external and internal recti should always be known before prescribing convex or concave spherical lenses. This should be determined when the eyes are uninfluenced by a mydriatic.* The superior and inferior recti and the obliques may not be consulted when glasses are to be prescribed.

In prescribing spherical lenses for

Esophoric Cases

there is an absolute need for the mydriatic in its full power, regardless of whether the refraction is hypermetropic or myopic. If hypermetropia is associated with esophoria, the

* See *Ophthalmic Record*, Vol. II., No. 11.

accommodation should be fully suspended, not only that the whole of the refractive error may be known, but that it also may be corrected fully. Such glasses will cure a part (the pseudo-esophoria) of the esophoric condition, if not all. As I have been able to show in a former study, the esophoria associated with uncorrected hypermetropia is not all due to the intrinsic power of the internal recti. Further observation leads me to suggest that, for every dioptre of hypermetropia in each eye, there is a half degree of pseudo-esophoria (1 D. of H. in each eye would give one degree). What esophoria is left after giving a full correction of the hypermetropia must be cured by operation or exercise, or by both. A full correction of the hypermetropia should always be given in cases of internal squint.

When esophoria is associated with myopia, the mydriatic should be used to full suspension of accommodation, that the very great error of giving an over-correction of the myopia may be avoided. The exact correction should be known and recorded. The same may be prescribed for distant seeing without risk of adding a pseudo-esophoria to the true muscle error; but the fully correcting concave lenses should not be prescribed for near use, for the reason that the muscle error would be thereby increased.

When the esophoria has been cured, the full myopic correction should be worn for all distances. In prescribing spherical lenses for

Exophoric Cases

there is an absolute need for the mydriatic in its full power, whether the refraction is hypermetropic or myopic; for it is in these cases that the true error of refraction is most likely to be concealed, because of the spasm of accommodation caused by the exophoria. Exophoria often causes emmetropic eyes to appear to be myopic. It renders latent the greater part of a hypermetropic error, and adds a pseudo-myopia to the real myopia. The mydriatic alone is able to show the refraction of exophoric eyes in its true state. Without it concave lenses will be selected by emmetropic eyes; not infrequently, under these conditions, hypermetropes choose concave lenses. While an over-correction of myopia should never be given, the *full* correction of a myopia associated with exophoria should always be prescribed, and the patient should be directed to wear these lenses for all purposes of vision.

While the hypermetropia associated with exophoria should always be known and recorded, the full correction should not be given—often no correction—until the muscle error has been cured by the means at our command.

Orthophoria is rare; but when it exists, a full correction of any and all refractive errors should be given. That an over-correction of myopia and an under-correction of hypermetropia may be avoided in these cases, the full suspension of accommodation is essential.

Instead of using the mydriatic once in forty-six cases, have we not strong scientific reasons for using it forty-six times in forty-six cases?

The human eye remains a human eye under the influence of the mydriatic, except as to its focal adjustment; in this respect it is no more than a machine, and is susceptible of perfect measurement by means of our several objective and subjective methods. In no other way can accuracy be obtained.

The unscientific cry of honest but misguided oculists against the use of the mydriatic is, to the ear of the quack spectacle vender, a sweet sound which he attunes to his own profit and to the detriment of the unsuspecting public. May it soon be heard no more in the land!

PART III.

OPERATIONS.

MUSCLE SHORTENING VS. MUSCLE ADVANCEMENT.*

IN doing advancement operations on the recti muscles, one of the chief dangers to be considered is turning the eyeball on its antero-posterior diameter, in such a way as to throw unbearable strain on either the superior or inferior oblique muscles. In addition to the danger of "twisting" the eyeball, there is the additional danger that the knots may slip, or the threads may cut the conjunctiva and sub-conjunctiva before strong adhesions have taken place between tendon and sclera; and thus the divided tendon may be pulled back even beyond the point of its original attachment, when the patient's condition will be worse than before the operation. In DeWecker's advancement operation the middle fibres of the tendon, which are not divided, will prevent the tendon's going back very far in case the knots slip or the threads cut.

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Of all advancement operations, DeWecker's is least objectionable, for the reason that the two things to be dreaded are less likely to occur.

Believing DeWecker's operation to be the best of its class, and thinking that some readers may not have seen it described, I venture here to give my understanding of the technique of this operation. The conjunctiva is incised vertically over the insertion of the tendon, sufficiently to expose it well. Now the upper and lower two-fifths of the tendon are divided at their insertion, while the middle one-fifth is left uncut. With one needle and one thread the upper divided part of the tendon is advanced, the needle being made to penetrate first the tendon, then the conjunctiva and subjunctiva above and toward the cornea. A similar stitch is then taken through the divided lower part of the tendon and the conjunctiva and sub-conjunctiva below. In tying these stitches sufficient force is exerted for advancing the cut parts of the tendon as far as the judgment of the operator may decide. The stitches are allowed to remain in four to six days, depending on the amount of reaction. The undivided part of the tendon serves a double purpose: 1. It prevents, to a great extent, the setting of the tendon too high or too low, and in that much avoids "twisting" the eyeball on its antero-posterior axis. 2. Should the knots slip or the threads cut their way out too soon, these undivided fibers prevent the tendon from going very far back behind the original point of attachment. This partial advancement reminds one of Stevens's partial tenotomies, the one being the reverse of the other.

DeWecker's *advancement*, the best of all operations of this class, has been described, so that a fair contrast may be drawn between it and my own *shortening* operation.

My operation for *shortening* a rectus muscle is simple, effective, and free from the two prominent risks incurred in any of the *advancement* operations. In this, as in many other operations on the eye, cocaine anesthesia can be relied on. The first step of the operation consists of a vertical conjunctival incision one-eighth of an inch behind the insertion of the tendon and a little longer than the muscle is wide. From the lower extremity of this cut a horizontal conjunctival incision is made one-fourth of an inch long, near to, and parallel with, the lower border of the muscle. The triangular flap of conjunctiva is now dissected up, and is held out of the way by an assistant. The second step of the operation consists in making a puncture through the capsule at the lower border of the tendon and passing a strabismus hook beneath it and then making a slight puncture of the capsule at upper border for the exit of the point of the hook. Everything is now ready for the last operative procedure, the taking of the stitch for shortening the muscle. A thread is armed with two needles slightly curved. One needle is passed through the muscle from its outer surface and is brought out beneath the lower border of the muscle; the other is passed in the same way, but is brought out beneath the upper border of the muscle. The capsule is included in this stitch. The amount of tissue thus included in the loop need not be more than one-fourth the width of the muscle; and the distance of this loop behind the insertion of the tendon must depend on the amount of shortening desired. The muscle is held away from the globe by fixation forceps while the needles are being passed as above indicated. The operator now taking the hook into his own hand draws it slightly back, and at the same time gently lifts the tendon from the globe. He now takes needle No. 1, and pierces the tendon from the ocular side, at its point of insertion and between the center and its lower border, bringing it out through the conjunctiva over the insertion, then removes the needle. In a similar way needle No. 2 is passed through the tendon between its center and upper border and is brought out through the conjunctiva over the insertion. This needle is then removed. The two ends of the one thread need not be more than one-eighth of an inch apart as they emerge from the tendon. On tying the knot in the usual way, that part of the muscle at the loop is brought in contact with the tendon at its insertion and is there confined by completing the knot. The triangular flap of conjunctiva is now allowed to fall and cover in the exposed muscle, including its "tuck." The stitch is allowed to remain from four to six days, depending on the inflammatory action excited. The stitch will excite sufficient inflammation to bind the parts in their new relationship; and thus the shortening is made permanent. As in *advancements* so in the *shortening*, it is often necessary to do either a partial or a complete tenotomy of the opposing muscle.

A muscle thus shortened is not likely to "twist" the eyeball; if the twisting occur, it would be but slight as compared with the result of an ordinary advancement. The stitch taken in the tendon will not cut its way out, as is so common when taken in the conjunctiva and sub-conjunctiva, therefore there will be no slipping back of the muscle from this cause. Should the knot untie, the muscle cannot go farther back than before; for no part of it has been cut loose from its original attachment. The "knuckle of muscle" made by the operation undergoes absorption, so that in a few weeks the parts become smooth at the site of the operation.

The operation described above I have done many times, with much satisfaction. Even if it had been devised by some one else, I think I would still prefer it over the very best advancement operations, and for the reasons given.

INDICATIONS FOR, AND ADVANTAGES AND TECHNIQUE OF, MUSCLE SHORTENING.

In the judgment of the author of this paper, muscle shortening is indicated in all cases of heterotropia, regardless of the direction or extent of the turning. In many cases of low degrees of squint, the shortening operation alone will effect a cure; while, in a greater number of cases, the shortening of the weaker muscle should be associated with a partial division of the tendon of the stronger muscle, in order to the attainment of the best results. In cases of high degree of exophoria, in which a partial tenotomy of both external recti does not reduce the exophoria within the range of possibility of completing the cure by rhythmic exercise of the interni, the latter should be shortened. In all cases of exophoria, with less than 8° of abduction, shortening of the interni is indicated, not to be associated with even the slightest tenotomy of the externi. In high degrees of esophoria, not reduced by a partial tenotomy of the interni within the limit of possibility of completing the work by exercising the externi, the latter should be shortened; while in the lower degrees of esophoria, the only operation indicated is the shortening of the externi. In any case of hyperphoria, not reduced to 2° or less by a partial tenotomy of the superior rectus of the hyperphoric eye, the inferior rectus of that eye should be shortened. In all cases where shortening is indicated, except in hypertropia and hyperphoria, the operative effect should be divided between the corresponding muscles of the two eyes. The superior and inferior recti of a cataphoric eye should be operated on rarely if ever. Since the shortening of the recti muscles, associated with partial tenotomies of the opposing muscles can effect so much, a complete tenotomy of an ocular muscle cannot be often indicated.

THE ADVANTAGES OF SHORTENING

a muscle over the older method of muscle advancement may be set forth in a few words. The former is the more easily done, and is the safer of the two operations, in that torsion of the eye is not so likely to occur as a result of setting the tendon too high or too low, in case the externi or the interni are the muscles involved; or too far out or in, when the superior and inferior recti are the muscles in question. Should the knot come untied in the shortening operation, the patient's condition will not be worse after the operation than before, which cannot always be said when the same thing happens in the attempt to advance a muscle. An apparent objection to the shortening operation is the knuckle of the muscle formed by the folding. This disappears by absorption.

THE TECHNIQUE OF MUSCLE SHORTENING

was simple when first introduced, but has grown in simplicity as a result of a modification suggested and practiced by Dr. Tenney, of Boston. The original operation was performed as follows: The eye was cocainized; the lids were separated by a stop speculum; the conjunctiva was seized with fixation forceps a little behind the insertion of the muscle tendon, and two cuts with scissors were made: one vertical the entire width of the tendon and a little behind the insertion, the other below and parallel with the lower border of the tendon and muscle. The included portion of the conjunctiva was then dissected up and held out of the way. A puncture of the capsule of Tenon was next made, at the lower border of the tendon near its insertion, and another puncture at a corresponding point at the upper border of the tendon, through which a strabismus hook was passed beneath the tendon, with which to control the eye. A silk thread was then armed with two needles, one of which was passed through the upper part of the muscle and capsule from without in, at a chosen distance behind the insertion, and similarly the other needle was passed through the lower part of the muscle and capsule at a point immediately in line with the first. Drawing on the two ends, a loop of thread was brought in contact with the capsule over the muscle. The passage of these needles was facilitated by lifting the respective borders of the muscle with fixation forceps. The next step of the operation was to lift the tendon by means of the hook, and pass first one needle and then the other through the tendon from within out at points one-eighth of an inch apart, bringing these needles out through the conjunctiva a little in advance of the tendon insertion. The two needles were now removed, and by means of the surgeon's knot the part of the muscle beneath the loop of thread was drawn up to the insertion of the tendon, thus shortening the muscle to a corresponding extent. The flap of conjunctiva was now allowed to fall down over the knuckle of muscle. The stitch was allowed to remain from four to six days, at the end of which time the muscle was fixed, by adhesive inflammation, in its new relation.

The modification suggested by Dr. Tenney in a personal letter I at once adopted. As thus modified the operation is done as follows: A horizontal cut is made with scissors through the conjunctiva and capsule of Tenon, beneath the lower border of the muscle, from the insertion of the tendon backward, to the extent of the shortening desired. Through this cut, two strabismus hooks are passed: one beneath the tendon at its insertion, the other beneath the muscle. By means of these hooks the muscle is lifted from the sclera. A needle is now passed through the conjunctiva and the upper border of the tendon at its insertion, and is carried back beneath the muscle to a point chosen just in advance of the second hook, where it is made to penetrate the muscle near its upper border and the superposed capsule and conjunctiva. The needle was then made to reënter the puncture in the conjunctiva made by it in its exit, is directed downward between the conjunctiva and the capsule, and is brought out through the incision in the conjunctiva. Then the lower border of the muscle and capsule are seized with forceps, and this needle is made to penetrate them from without in, and is again brought out through the horizontal incision. The needle is now passed through the incision beneath the tendon, which it is made to penetrate at the lower border of its insertion, and is brought out through the conjunctiva at a point in line with, and one-eighth of an inch below, the primary puncture. The two ends of the suture thus passed are now brought together by a surgeon's knot with enough force to bring the part of the muscle beneath the loop in contact with the tendon. The suture is allowed to remain from four to six days.

The suture plate, as modified and improved by Dr. George H. Price, will most likely be of much service in this operation, if for no other reason than that it will greatly facilitate the removal of the suture. The improved plate is made of aluminum, is five-sixteenths of an inch long, and one-eighth of an inch wide, oval in shape. In this plate there are two holes one-eighth of an inch apart, through which the two ends of the suture are passed. In trying the suture, the plate, which has such a concavity as to fit the curvature of the eye, is brought in contact with the eye, and the knot is tied over it between the two holes. There is a transverse groove near one hole, along which one blade of the scissors in passed when the suture is to be removed.

A NEW OPERATION FOR PTERYGIUM.*

Perhaps every operator who has had much experience in

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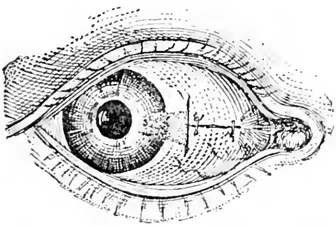
removing this growth has now and then seen it return in spite of the care exercised in the operation. It is generally conceded that the return of the growth is due to some part of the ocular conjunctiva attaching itself to the denuded surface of the cornea; and, with this thought in mind, operators are usually careful not to cause the conjunctiva to overlap the cornea, when they bring the margins of the conjunctival wound together with stitches. The object of this publication is to call attention to a little device of my own, as effective in preventing a return of the growth as it is simple in execution. The growth can be removed in any one of the several ways recommended by different operators. This done,



my device consists in making a vertical incision above and below, each about one-eighth of an inch long and about one-tenth of an inch from the most projecting part of the denuded margin of the cornea. Before the vertical cuts are made, the two conjunctival stitches should be taken in the usual way for covering the exposed sclera. When these are tied, the parts are brought together without throwing the conjunctiva near the corneal margin into folds. As can be seen, there is the minimum of danger that any of the conjunctiva will become attached to the cornea before it is covered by epithelium.

For the best results in the way of leaving a clear cornea, the corneal part of the pterygium should always be removed by traction, never by dissection. My method of removing the growth is to seize the pterygium with fixation forceps at the corneo-scleral junction; lifting it gently, I make punctures with a Gräfe knife through healthy conjunctiva immediately above and below the growth at the corneal margin. Through the puncture below, while still holding the growth with the forceps, I pass one blade of a straight pair of scissors toward the canthus sufficiently far to include all that I wish to remove, and bringing the two blades together I make the first incision obliquely up. In a similar way I enter the puncture above, and cutting obliquely down and toward the canthus, complete a V-shaped incision. The part of the growth thus included is carefully dissected up to the corneal margin, but no farther. Grasping this freed portion of the pterygium firmly with the fixation forceps, I direct the patient to look strongly in the direction of the base of the growth while I make forcible traction toward its apex. In this way the removal is easily effected without leaving any shreds behind. This is infinitely better than the most careful dissection could be. Irregularities of the denuded surface are soon filled in with plastic material, and the whole is covered by epithelium in very few days.

ARTIFICIAL PUPIL THROUGH THE CENTER OF SOFT CATARACT.

In 1888 I published in the *Nashville Journal of Medicine and Surgery* a description of the above-named operation, using as an illustration the accompanying cut, which was made from life. The patient on whom I did the first operation (the one represented in the cut) was a girl about sixteen years old, who had been blind for four or more years, the cataract developing after an attack of typhoid fever. After the usual method described in text-books, I made the first opening in the capsule of each eye with one needle; after resulting irritation had passed away, I made a second operation with one needle, stirring up the lens substance somewhat, so as to hasten its solution. By the end of another two weeks a considerable portion of each lens had been dissolved, and no excitation had followed the second operation. Now, with the view of still further hastening the solution of the cataracts, I again introduced one needle to stir the lens substance. While the needle was in the first eye the thought occurred to me that it would be safe to introduce a second needle and, bringing the two together in the center of the partly dissolved cataract, make an opening through it by a process of tearing and packing the substance toward the ciliary processes, without danger of pressing against them. I called for a second needle and at once put the thought into execution in that and the fellow-eye, and with the results shown in this cut.

The patient was able to see at once; and hardly any irritation followed the operation. I watched anxiously, fearing that the lens material might become loose and fill the opening I had made. On the contrary, by the solvent action of the aqueous the opening was made larger day by day.

SAVAGE'S ARTIFICIAL PUPIL THROUGH CENTER OF SOFT CATARACT

Within a week after making the pupils I had fitted my patient with lenses, giving her vision = $\frac{20}{xx}$, and sent her home. She went about seeing while the remaining parts of the cataracts were undergoing solution, which took several weeks longer.

I have since done the operation often, and always with success. Similar reports have come to me from others.

The opening should not be made, in the manner described, earlier than the third needling, which, as a rule, is from four to six weeks after the first operation; and not then unless about half the material has been dissolved. The danger in attempting it too early would be that the packing process might cause undue—even injurious—pressure on the ciliary body.

THE SIMPLEST AND BEST OPERATION FOR THE CURE OF ENTROPION AND TRICHIASIS.

At the time I described my double-stitch method of operating for the cure of entropion,* I was not aware that Dr. John Green had preceded me in the device of this most effective means of everting the ciliary margin, after either a simple Burow incision or a Flarer's inter-marginal incision.

My method of operating at that time is shown in the accompanying cut A, which I reproduce.

As may be seen, I made the inter-marginal incision, and then took several double stitches as shown, tying first the middle suture and then those on either side. The stitches were not removed until the wedge-shaped incision had become filled with plastic material. The chief difficulty in

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*In *Nashville Journal of Medicine and Surgery*, early in 1888.

this operation was in making the inter-marginal incision, because of the narrowed and otherwise deformed lid margin. For this reason I soon abandoned Flarer's incision, and associated the double stitch with Burow's incision, as Green had before done, but not to my knowledge. My stitch always differed from Green's, in that I made the needle enter

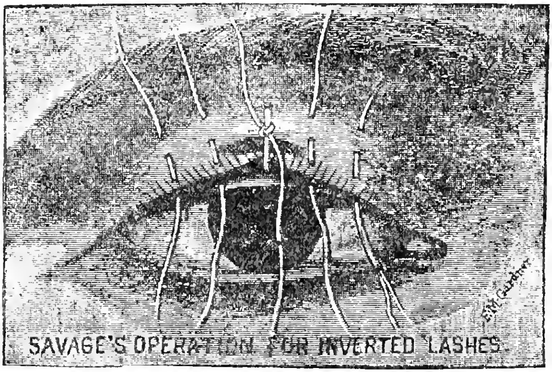


Figure A.

the Burow incision, as I had before made it enter the Flarer incision, and thus included structure that the thread was not likely to cut through. Green's first stitch was taken to only a slight depth through the outer lip of the lid margin, and therefore readily cut its way out, often too soon. Our second stitches are identical. I continued to do this operation until a year ago, when the thought of a most important modification occurred to me, a description of which was published in No. 7, Vol. II., of the *Ophthalmic Record*. Cut B shows the modification, and the reasons for it will be apparent.

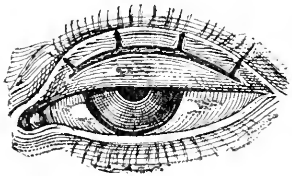


Figure B.

Having made the Burow incision in the usual way, I then made four vertical cuts through the freed margin of the lid through all the structures to the skin. While the Burow incision widens the deformed tarsus, the vertical cuts lengthen the freed marginal part of the tarsus (I am not sure but that the vertical cuts should extend entirely across the tarsus), which is a great gain. A great advantage gained by the vertical cuts is that they greatly facilitate the out-turning of the eyelashes, so that the Burow incision may become filled with a large mass of plastic material. Another decided advantage is that, in most cases, the double stitch—all stitches—may be dispensed with. The accompanying cut C, shows how effectively the lid margin may be held in the everted position by means of a narrow strip of surgeons' rubber adhesive plaster. The use of the plaster was suggested to me by my office associate, Dr. George H. Price. I have constantly employed the plaster in connection with the longitudinal and vertical cuts for about

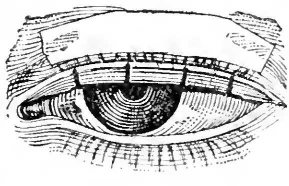
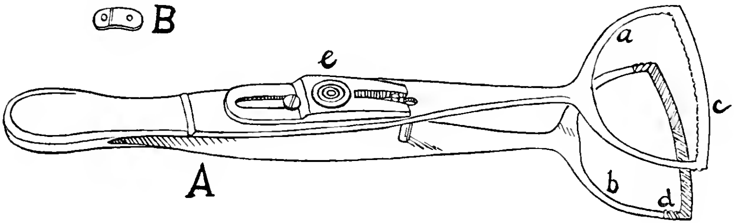


Figure C.

one year. There are few operations that are more uniformly successful. With the T-shaped forceps and a sharp knife, the operation is quickly and easily performed. When the eyelashes are short and few, the double stitch must be substituted for the plaster.

Finding the T forceps not all that could be desired, I devised the stirrup forceps shown in the accompanying cut. In every way the latter is superior to the former. The lid,



when properly grasped with the stirrup forceps, is easily manipulated. The shoulders extending from the foot piece a short distance up each arm of the stirrup, serve to compress the margin of the lid so as to render the operation a bloodless one. Free bleeding occurs after the removal of the forceps. The Burow incision should be made obliquely from within out and toward the free margin of the lid, and only far enough within the lid to avoid wounding the hair follicles. The incision should include the entire length of the cartilage. One vertical cut at each end of the Burow incision is usually enough.

TO NARROW THE PALPEBRAL FISSURE.

THE operation for narrowing and shortening the palpebral fissure is not often necessary, but when we have it to do we want it to be successful. Paring the margins of the upper and lower lids at the outer canthus by means of scissors or knife is not always easily and thoroughly done. Some epithelial cells are left that prevent strong and extensive adhesions, after the most careful stitching. Partial or complete failures are frequent as compared with the number of these operations.

I had a patient recently whose facial nerve had been wounded when a child, after which he had not been able to close the eye of that side. During waking hours that eye was always more widely open than the fellow-eye. To relieve him of this deformity and to give better protection to the cornea, I advised an operation. The attempt after the usual method was a failure. He was willing to try again, but wanted no failure this time. It occurred to me to use the galvano-cautery in order to get the two raw surfaces. After cocainizing the eye, I protected the globe with the horn spatula and applied a cautery point of proper length and width, and made a free burn on lid margin behind the lashes. I made a similar burn on the fellow-lid. I then removed the charred tissue by scraping with a knife, and stitched the two raw surfaces together. Perfect adhesion formed, and the result was good.

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